Study of the Starting Torque In a Polyphase Synchronous Motor

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Study of the starting torque
in a polyphase synchronous

STUDY OF THE STARTING TORQUE IN A POLYPHASE SYNCHRONOUS MOTOR.

A THESIS PRESENTED BY

H B Marshall

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to the

PRESIDENT and FACULTY

of the

ARMOUR INSTITUTE OF TECHNOLOGY

for the degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING,

Having completed the prescribed course of

study in Electrical Engineering.

Chicago, June 15th, 1905.

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STUDY OF THE STARTING TORQUE IN A POLYPHASE SYNCHRONOUS MOTOR.

A synchronous motor, although its field is narrow, nevertheless has a field distinctly its own, wherein no other machine could be used. This field though small, occupies such an important place in large systems that extended experiments have been made to enlarge this field.

Any alternating current generator may be used as a synchronous motor. The difference lies in the fact that the former converts mechanical to electrical power, while the latter reverses the operation. A synchronous motor operates in series with its generator, and a generates a counter electromotive force which opposes that of the generator. The magnitude of this E. M. F. generated in the motor depends directly upon the field excitation. By increasing the field excitation sufficiently, this C. E. M. F. may be made of considerably greater value than that of the generator. On the other hand, by properly decreasing the field excitation, a proportionately low C. E. M. F. may be obtained. In the first case the phase of the current will be found to be in advance of the impressed voltage, and in the second case to be lagging behind. It is seen, therefore, that by simply changing the strength of the exciting current, the

armature current can be made lagging, in phase with, or in advance of, the impressed E. M. F. Hence it is possible to obtain any power factor for a given condition of load. In other words, the amount of current consumed by the motor depends upon the field excitation.

This property of the synchronous motor of producing at will any displacement of phase relation between current and E. M. F., furnishes a means of annulling the reactance due to the inductance of the line, and also at the same time, of compensating for a certain amount of lagging current due to inductive loads in other parts of the circuit. It will take care of a total current made up of energy and wattless components to an extent equal to its rated ampere out-put.

The synchronous motor, especially in units of large output, possesses a number of features which make its use at times preferable to that of the induction motor. The most important features are, (1), the ability to maintain a high power factor under various conditions of load; (2), the advantage of an unvarying speed, due to the inherent quality of the machine to run in synchronism with the generator; (3), the efficiency, which is as a rule found to be much higher than that of induction motors.

As a partial off-set to these advantages, the synchronous motor is not adapted for use where a large

starting torque or frequent starting of the load is necessary, and cannot be used where a variable speed is required, as it does not admit of independent speed regulation. It also requires skillful and intelligent attention, as well as certain station appliances, and also a separate current for excitation. Another objection to the synchronous is its tendency to hunt, of which we shall speak latter. In all large stations, where a portion of the load is inductive, it is customary to install synchronous motors in preference to any other for the operation of the minor machinery of the plant, the motor also being used to maintain a high power factor in the feeder system.

As mentioned above, one of the main disadvantages of the synchronous motor is its inability to start under load, due to its low starting torque. With this in view, this investigation was undertaken to determine the conditions giving the highest torque. A synchronous motor upon starting acts somewhat as an induction motor, and takes a comparatively large lagging current from the line, the magnitude of the current being limited by the impedance of the armature. If the size of the motor is such that it requires an excessive starting current, thereby producing a large drop in the line, special devices for starting must be resorted to. However, when the size of the motor is small compared to that of the generator, connection

may be made directly to the mains, with the fields unexcited, the load not being applied until synchronism is reached.

The method as stated above is the one most usually employed. The following are some of the possible conditions holding true for all sizes of machines: (1), fields open, (2), fields shorted individually, (3), fields shorted as a whole, (4), squirrel cage attachment placed on the fields poles, and (5), copper bands surrounding the pole shoes. Having the fields open is the customary method, and the motor startes as an induction motor with a small torque, due to the induced currents in the pole pieces, and will soon speed up to almost synchronism. It is quite ev evident that at starting the torque is extremely small, and will not sustain any load. With the fields shorted individually, a modified form of an induction motor is produced, in that the field windings correspond to a small degree to the secondary windings of an induction motor. When the fields are shorted as a whole, this idea is carried out in a slightly different manner, giving a different modification of the induction motor windings.

The idea of a cage attachment, similar to the squirrel cage rotor of an induction motor, seemed to be quite feasible, in that it might more nearly approach an

induction motor effect, giving a large torque at starting similiar to that of an induction motor, and as this torque would be additive it would reduce the time required for the machine to come to synchronism, and might enable it to start under load. This arrangement would not detract from the merits of the synchronous motor, in that after synchronism had been reached, and the fields excited, the cage would have no effect upon the operation of the machine, providing it remained in synchronism. If however the machime fell behind synchronous speed,the squirrel cage would again be brought into action, and would add to the torque of the machine, thus tending to bring the machine back to synchronous speed. This action would similarly be noticed, if the machine should speed above synchronous speed. Since hunting is an oscillation of speed above and below synchronism, the above arrangement would become a dampening device, and would considerable decrease the hunting. This in itself wouldbe a most beneficial characteristic. Another advantage which the cage attachment seemed to present was that of an increased power factor due to the large secondary currents that would be induced.

The relative position of the rotor to the stator might also be expected to give a variation in the starting torque.

MEASUREMENT OF THE STARTING TORQUE.

Various methods are applicable to the measuring of starting torque, but the one which appeared most suited to our purpose was an acceleration and moment of inertia method. Since the starting torque is equal to the product of the acceleration and moment of inertia, it may be obtained by determining these two factors. The moment of inertia may be obtained mathematically, but this could not be accurately done, due to the shape and heterogeneous character of the mass. It might also be determined by the torsion method, that is suspending the armature vertically by a steel wire, and after setting it into torsional vibration, measuring the number of oscillations in a given time. Due to the impossibility of removing the rotor on account of the construction of the machine, this method could not be used.

The method finally adopted was to measure the acceleration produced by impressing a definite torque upon the rotor, this torque being obtained by the action of gravity upon a known mass, which was suspended by means of a cord wound about the pulley wheel. The rim of the wheel was covered with lamp black, and a stylus attached to an electrically driven tuning fork was adjusted so that it would trace a curve on the surface of the wheel as it

revolved. This tuning fork was a standard, and carefully calibrated to give fifty vibrations a second. Since the time of each vibration is known and constant, we can determine the relation between the angle passed through and the time. This angle was measrured by a disk graduated in degrees, securely fastened to the end of the pulley wheel. The average velocities during consecutive equal periods of time can thus be determined, and the acceleration ascertained. In accurately determining the moment of inertia it is necessary to take the friction into account. This is found by determining the retardation given the wheel, when while running no force other than friction is acting. Adding this retardation to the above acceleration, the result is the acceleration which would be obtained were no friction acting. Since the acceleration and torque are known, the moment of inertia is determined by the following equation:-

$$I = \frac{T}{\omega}$$

where I is the moment of inertia in foot pound second units,

T is the torque impressed in foot pounds,

ω is the acceleration in radians per second per second.

From the following data, these results are obtained:-

Average acceleration per (.2 sec.)^2,----- 15.5 degrees

" retardation " " ,----- .28 "

Theoretical acceleration " ,----- 15.82 "

DETERMINATION OF THE MOMENT OF INERTIA.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.	AVERAGE ACCELERATION.
0	44.0			
10	51.0	7.2		
20	73.2	18.0	10.8	
30	110.0	36.8	18.8	
40	161.6	51.6	14.8	
50	228.0	66.4	14.8	
60	311.0	83.0	16.6	15.55
70	50.0	99.0	16.0	
80	165.0	115.0	16.0	
90	295.6	130.6	15.6	
100	82.8	147.2	16.6	
110	243.5	160.7	13.5	
120	44.6	161.1	.4	
130	207.0	162.4	1.3	
140	8.0	161.0	-1.4	
150	169.0	161.0	0.0	
160	329.8	160.8	-.2	
170	130.0	160.2	-.6	
180	289.5	159.5	-.7	
190	89.0	159.5	0.0	-.214
200	248.5	159.5	0.0	
210	47.5	159.0	-.5	
220	207.0	159.5	.5	

DETERMINATION OF THE MOMENT OF INERTIA.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.	AVERAGE ACCELERATION.
0	240.0			
10	149	9.0		
20	272.0	23.0	14.	
30	310.0	38.0	15.	
40	3.0	53.0	15.	
50	72.0	69.0	16.	
60	156.0	84.0	15.	15.50
70	256.0	100.0	16.	
80	12.0	116.0	16.	
90	145.0	133.0	17.	
100	278.0	143.0	10.	
110	72.0	144.0	1.0	
120	216.0	144.0	0.0	
130	359.0	143.0	-1.0	
140	142.0	143.0	0.0	
150	284.5	142.5	-.5	
160	66.0	141.5	-1.0	
170	209.0	143.0	1.5	-.2875
180	349.0	140.0	-3.0	
190	131.0	142.0	2.0	

DETERMINATION OF THE MOMENT OF INERTIA. (Continued)

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.	AVERAGE ACCELERATION.
200	272.0	141.0	-1.0	
210	52.0	140.0	-1.0	
220	193.0	141.0	1.0	
230	333.0	140.0	-1.0	
240	113.0	140.0	0.0	-.2875
250	252.0	139.0	-1.0	
260	30.5	138.5	-.5	
270	170.5	140.0	1.5	
280	308.0	137.5	-2.5	
290	86.1	138.1	.6	
300	224.5	138.4	.3	

Theoretical acceleration per (sec.)^2,------- 15.82 X 25

" " " " ,------- 395.5^o

" " " " ,------- 6.9 radians.

$$T = W r$$

where T is the torque in foot pounds,

W is the weight acting ---------- = 25 pounds.

r is the radius of the pulley wheel= .744 feet.

therefore

$$T = 25 \times .744 = 18.6 \text{ foot pounds.}$$

$$I = \frac{T}{\omega} = \frac{18.6}{6.9} = 2.70$$

The moment of inertia has now been obtained, and the relation and the torque and acceleration has been established. We are now able to determine the torque for various conditions by measuring the acceleration under those conditions. This was done as before, by means of the electrically driven tuning fork.

Before going further, a brief of the machine would not be out of place. The motor is of the A. T. B. style of the General Electric Co., and is rated at 7.5 K. W. at 80 volts and 25 cycles. It is of the six pole revolving field type, and is designed according to the following data:

DATA OF SYNCHRONOUS MOTOR #31773.

Style, ... A.T.B. 6 - 7.5 - 500 - 2 & 3 phase.

Capacity,.....7.5 K. W.

No. of poles, ... 6.

Cyclic speed, ... 25.

Speed, R.P.M., ... 500.

Volts, ... 80.

FIELDS.

Excitation, ... Separate.

Size of field wire, ... 15 B & S.

No. of turns in series per pole, ... 432

Mean length of turn in feet, ... 1.67

Outside diameter of punchings, ... 14.81"

Inside " " " , ... 3.5"

Length of punchings, ... 4."

Air gap, ... 0.94"

ARMATURE.

Armature windings, ... Distributed.

No. of circuits per phase, ... 3.

No of conductors in series per circuit,. 162. (3 phase)

" " " " " " " ,. 288. (2 phase)

ARMATURE. (Continued)

Size of conductors, ... 14 B & S.

two in multiple insulated as one twin d.c.c.

Arrangement per slot, horizontal, ... 6.

" " " , vertical, ... 8.

No of single coils, ... 36.

No. of slots, ... 36.

Size of slots, ... 1.56 X .55 inch.

Outside diameter of punchings, ... 24"

Inside " " " , ... 15."

Length of punchings, ... 4."

EXPERIMENTAL RESULTS.

Throughout the tests which follow, the machine was used as a three phase motor, with a voltage of 85, and a cyclic speed of 25.

The torque under the following various conditions was obtained: (1), fields open, (2), various field currents, (3), fields shorted as a whole, and (4), fields shorted individually. After these runs had been made, a cage attachment was placed upon the rotor. This apparatus was constructed along the lines of a squirrel cage rotor, the conductors and end rings being composed of number 4 copper wire. These conductors were placed on each side of the pole pieces and securely fastened by means of metal connectors to the end rings. Runs under the same conditions as without the cage were now made, the results of both sets of runs being as follows:-

Fields open, without cage, ...	82.5 ft. lbs.
" " , with cage, ...	113.1 " "
.25 ampere field current without cage, .	79.0 " "
.20 " " " with " , .	102.0 " "
.70 " " " without " , .	38.9 " "
.70 " " " with " , .	87.2 " "
1.2 " " " without " , .	27.2 " "
1.0 " " " with " , .	71.5 " "

Fields shorted as a whole, without cage, . 20.1 ft.lbs.

" " " " " , with " , . 51.6 " "

" " individually, without " , . 26.8 " "

" " " , with " , . 56.8 " "

From these results a number of interesting conclusions may be drawn. It has been maintained by some writers that a very slight excitation of the fields would increase the starting tirque. Our results, however, did not bear this out, and in fact showed the opposite to be true, the torque varying inversely with the field current.

It is interesting to note that with the fields shorted as a whole and individually, the starting torque was considerably less than with the fields open. From this we should conclude that the action of the field coils when shorted opposes that of the motor.

It is further noted that the action of the cage increased the starting torque in each case, the highest torque being developed with the fields open.

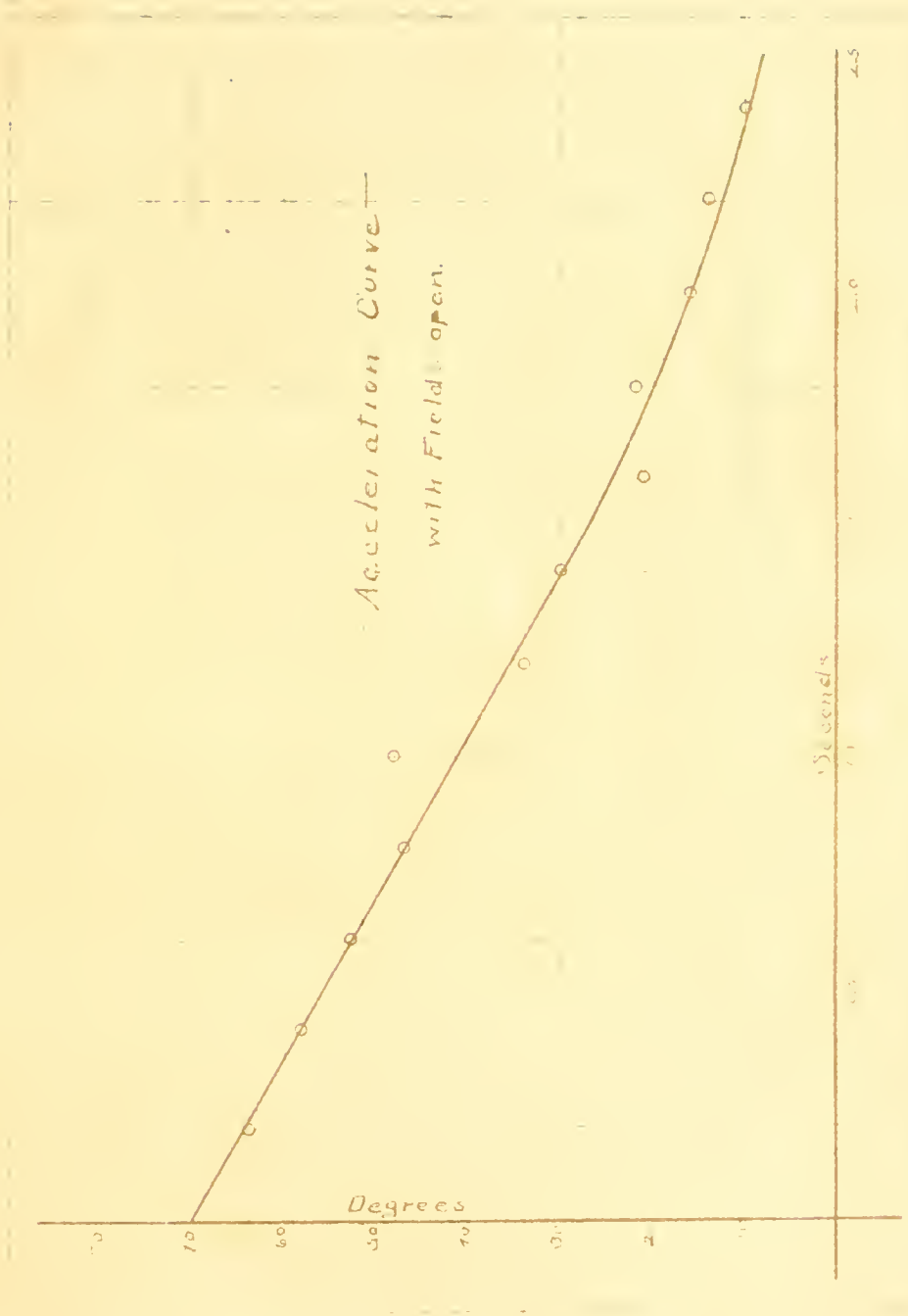
DETERMINATION OF STARTING TORQUE.

WITH FIELDS OPEN.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	25.0		
10	60.0	35.0	20.
20	159.0	99.0	64.0
30	316.0	157.0	58.0
40	166.0	210.0	53.0
50	63.0	257.0	47.0
60	8.0	305.0	48.0
70	347.0	339.0	34.0
80	356.0	369.0	30.0
90	26.0	390.0	21.0
100	78.0	412.0	22.0
110	146.0	428.0	16.0
120	228.0	442.0	14.0
130	320.0	452.0	10.0

Starting acceleration (from curve), --------- 70°

Starting torque, ---------- 82.5 ft. lbs.


Acceleration Curve
with Field open.
Degrees
Seconds

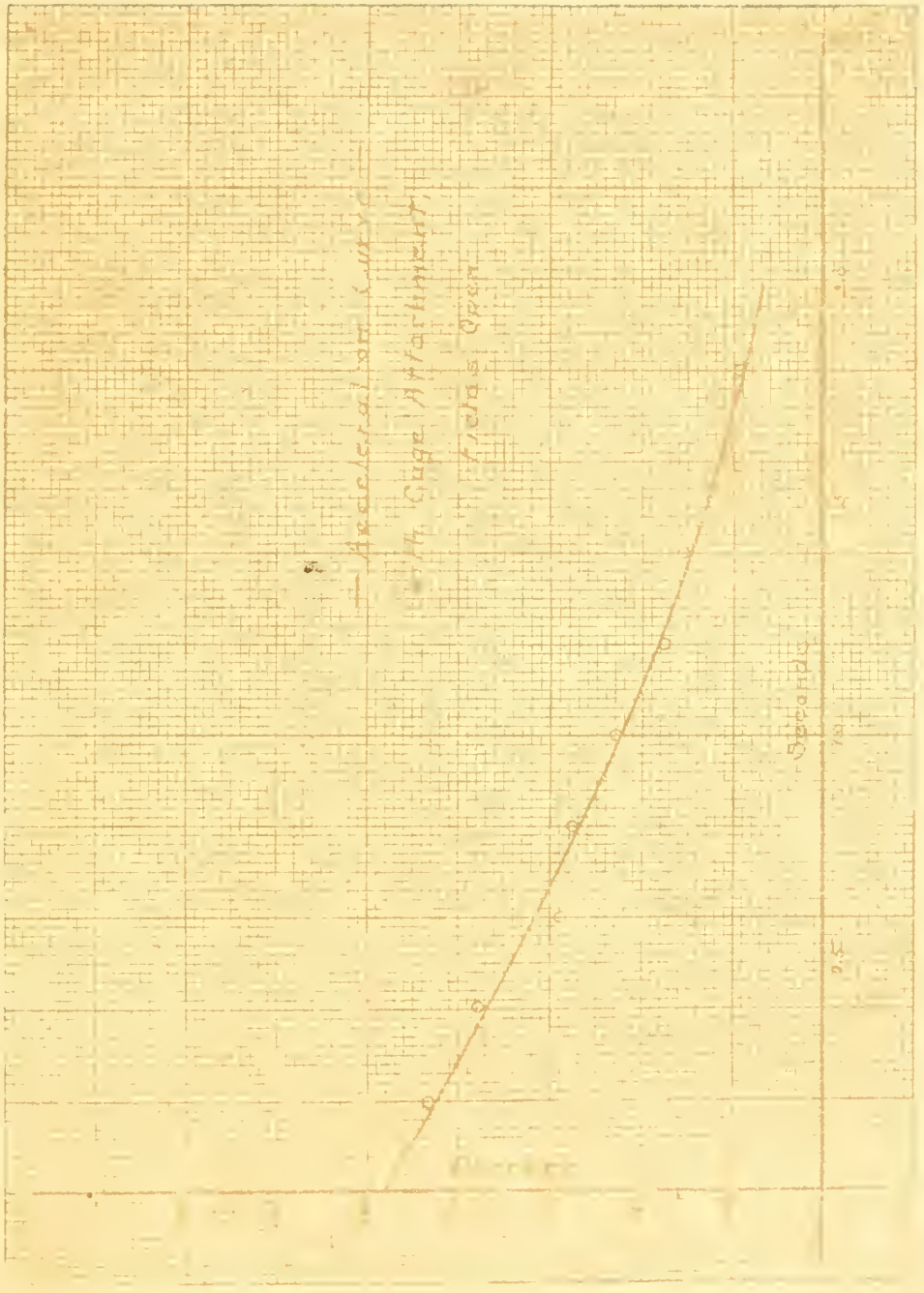
DETERMINATION OF STARTING TORQUE

CAGE ATTACHMENT, FIELDS OPEN.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR. ACCELERATION.
0	10.5		
10	53.0	42.5	
20	182.0	129.0	86.5
30	27.0	205.0	76.0
40	290.0	263.0	58.0
50	248.0	318.0	55.0
60	252.0	364.0	46.0
70	291.0	399.0	35.0
80	I.0	430.0	31.0
90	92.0	451.0	21.0
100	202.0	470.0	19.0

Starting acceleration (from curve), --------- 96^{o}

Starting torque, ---------- 113.1 ft. lbs.



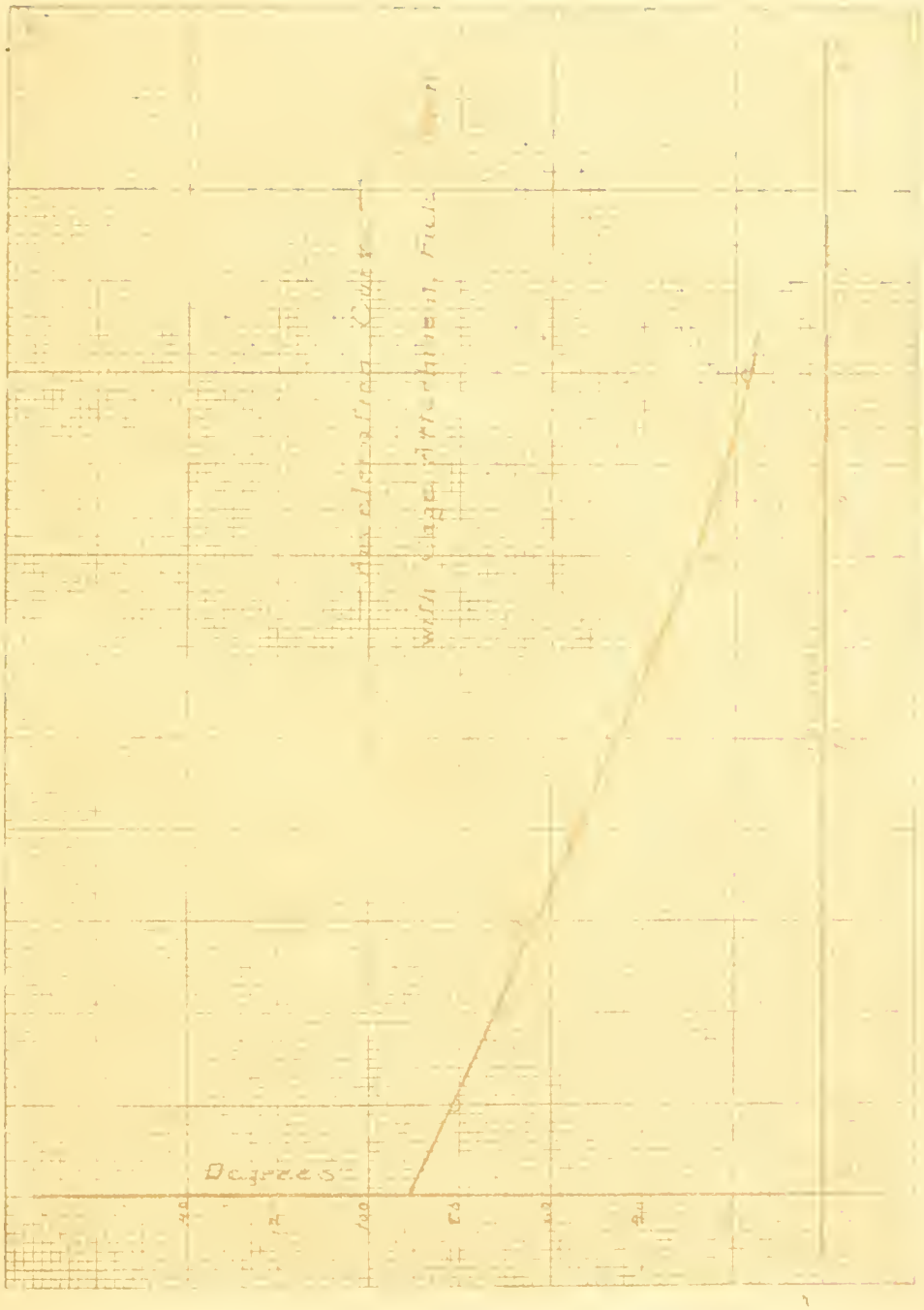
DETERMINATION OF STARTING TORQUE

CAGE ATTACHMENT, FIELDS OPEN.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	89.0		
10	133.0	44.0	
20	258.0	125.0	81.0
30	94.0	196.0	71.0
40	353,0	259.0	67.0
50	304.5	311.5	52.5
60	303.5	359.0	47.5
70	340.0	396.5	37.5
80	42.00	422.0	25.5
90	127.0	445.0	23.0
100	230.0	463.0	18.0

Starting acceleration (from curve), --------- 91^{o}

Starting torque, ---------- 106.0 ft. lbs.


Degrees

DETERMINATION OF STARTING TORQUE

CAGE ATTACHMENT, FIELDS OPEN.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	33.0		
10	75.0	42.0	
20	189.0	114.0	72.0
30	2.0	172.0	58.0
40	226.0	224.0	52.0
50	135.0	269.0	45.0
60	83.0	308.0	39.0
70	68.0	345.0	37.0
80	84.0	374.0	29.0
90	133.0	409.0	35.0
100	206.0	433.0	24.0
110	303.0	457.0	24.0
120	63.0	487.0	30.0
130	198.0	495.0	8.0
140	348.0	510.0	15.0

Starting acceleration (from curve), --------- 35^{o}

Starting torque,---------- 100.0 ft. lbs.

Degree

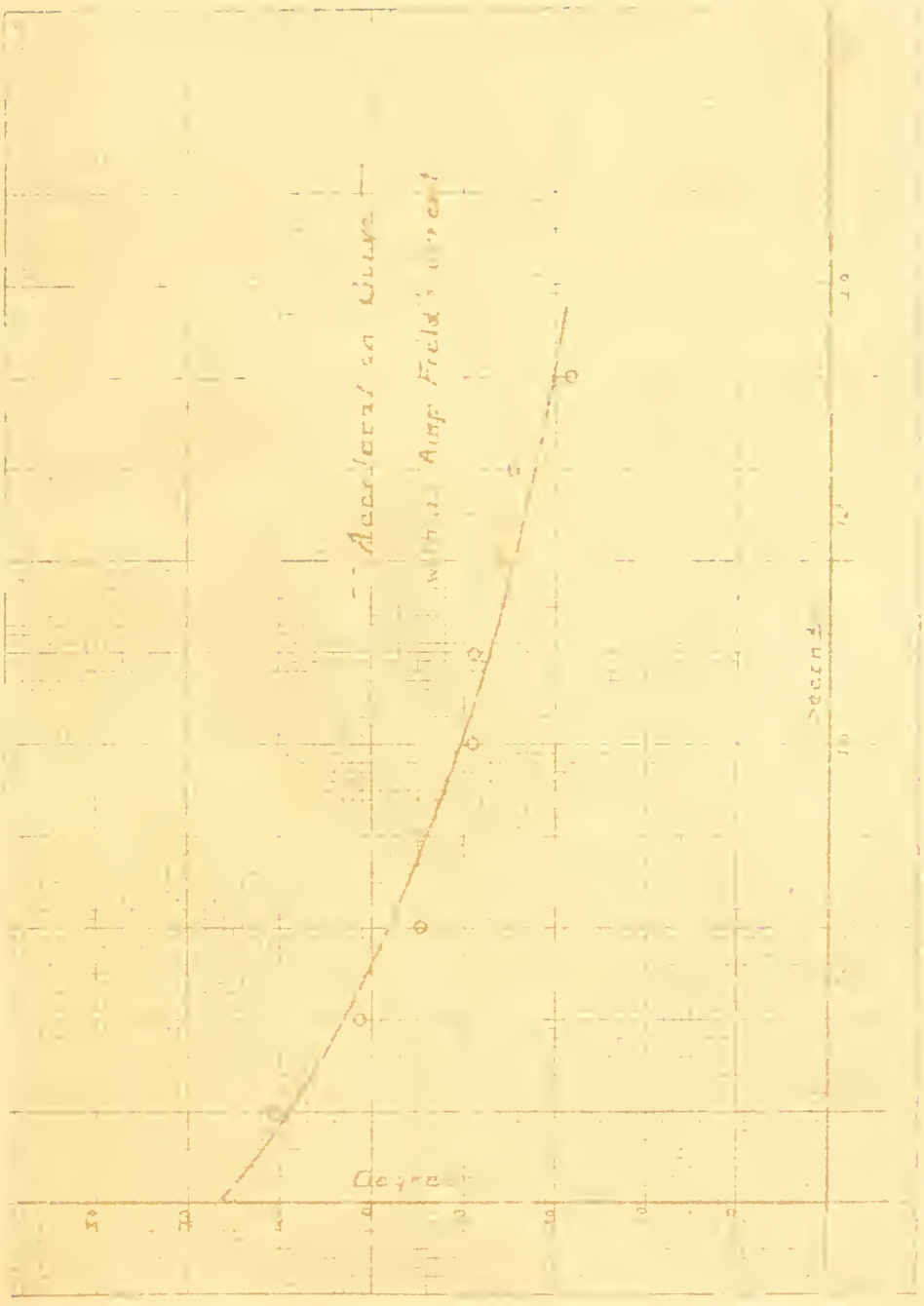
DETERMINATION OF STARTING TORQUE

WITH .25 AMPERES FIELD CURRENT.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	237.0		
10	266.0	29.0	
20	346.0	80.0	61.0
30	117.0	131.0	51.0
40	292.5	175.5	44.5
50	153.0	220.5	45.0
60	52.5	259.5	39.0
70	351.0	298.5	39.0
80	325.5	334.5	36.0
90	335.0	369.5	35.0
100	12.0	397.0	28.0

Starting acceleration from curve, -------- 67^{0}

Starting torque, ---------- 79.0 ft. lbs.


Acceleration in Curve
Second
Degree

DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, AND .2 AMPERE FIELD CURRENT.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	159.0		
10	206.0	47.0	
20	327.0	121.0	74.0
30	151.0	184.0	63.0
40	28.0	237.0	53.0
50	311.0	283.0	46.0
60	270.0	319.0	36.0
70	266.0	356.0	37.0
80	300.0	394.0	38.0
90	9.0	429.0	30.0
100	109.0	470.0	31.0

Starting acceleration (from curve), ------ 89°

Starting torque, ---------- 102.5 ft.lbs.

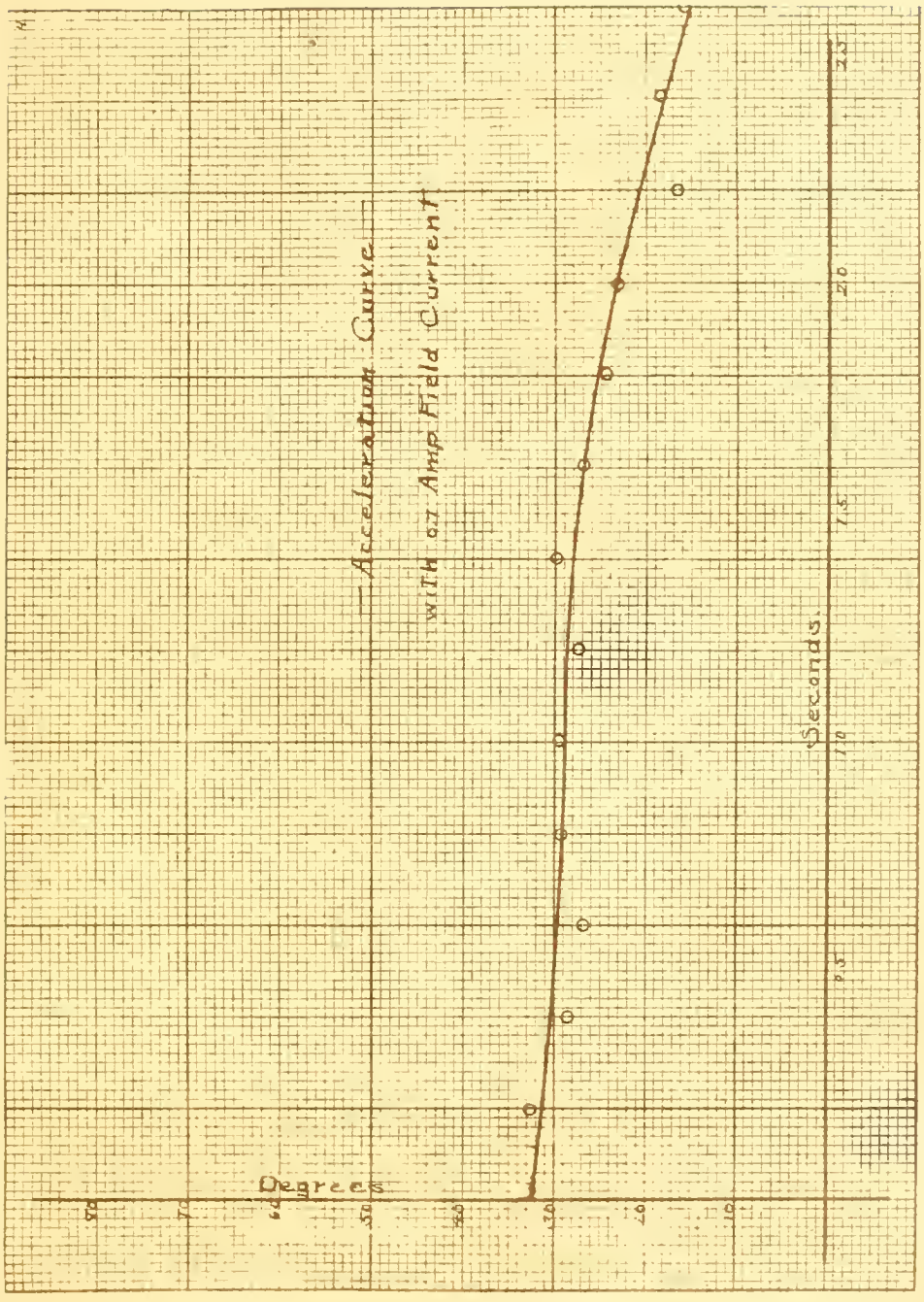
DETERMINATION OF STARTING TORQUE

WITH .7 AMPERES FIELD CURRENT.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	40.0		
10	56.0	16.0	
20	104.8	48.8	32.8
30	182.0	77.2	28.4
40	286.0	104.0	26.8
50	59.4	133.4	29.4
60	222.5	163.1	29.7
70	53.0	190.5	27.4
80	273.5	220.5	30.0
90	161.0	247.5	27.0
100	73.0	272.0	24.5
110	8.5	295.5	23.5
120	320.0	311.5	16.0
130	290.0	330.0	18.5
140	275.5	345.5	15.5

Starting acceleration (from curve), ------- 33^{o}

Starting torque,---------- 38.9 ft. lbs.


Acceleration Curve
with .07 Amp Field Current
Degrees
Seconds
70
60
50
40
30
20
10
2.5
2.0
1.5
1.0
0.5

DETERMINATION OF STARTING TORQUE

WITH 1.2 AMPERES FIELD CURRENT.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	265.0		
10	294.0	39.0	
20	353.0	59.0	20.0
30	77.0	84.0	25.0
40	184.5	107.5	23.5
50	315.0	130.5	23.0
60	111.0	156.0	25.5
70	292.0	181.0	25.0
80	139.0	207.0	26.0
90	11.0	232.0	25.0
100	263.0	252.0	20.0
110	174.0	271.0	19.0
120	101.1	297.0	16.0
130	42.0	301.0	14.0
140	355,0	313.0	12.0

Starting acceleration (from curve), --------- 23^{o}

Starting torque, ---------- 27.2 ft. lbs.

Deviation Curve
Within Amplified Current
Degrees

DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, AND 1.0 AMPERE FIELD CURRENT.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	159.0		
10	207.0	48.0	
20	309.0	102.0	54.0
30	100.0	151.0	49.0
40	291.0	191.0	40.0
50	162.0	231.0	40.0
60	65.0	263.0	32.0
70	356.0	291.0	28.0
80	310.0	314.0	23.0
90	279.0	329.0	15.0
100	264.0	345.0	16.0
110	265.0	361.0	16.0

Starting acceleration (from curve), ------ 60.5^{o}

Starting torque, ---------- 71.5 ft. lbs.

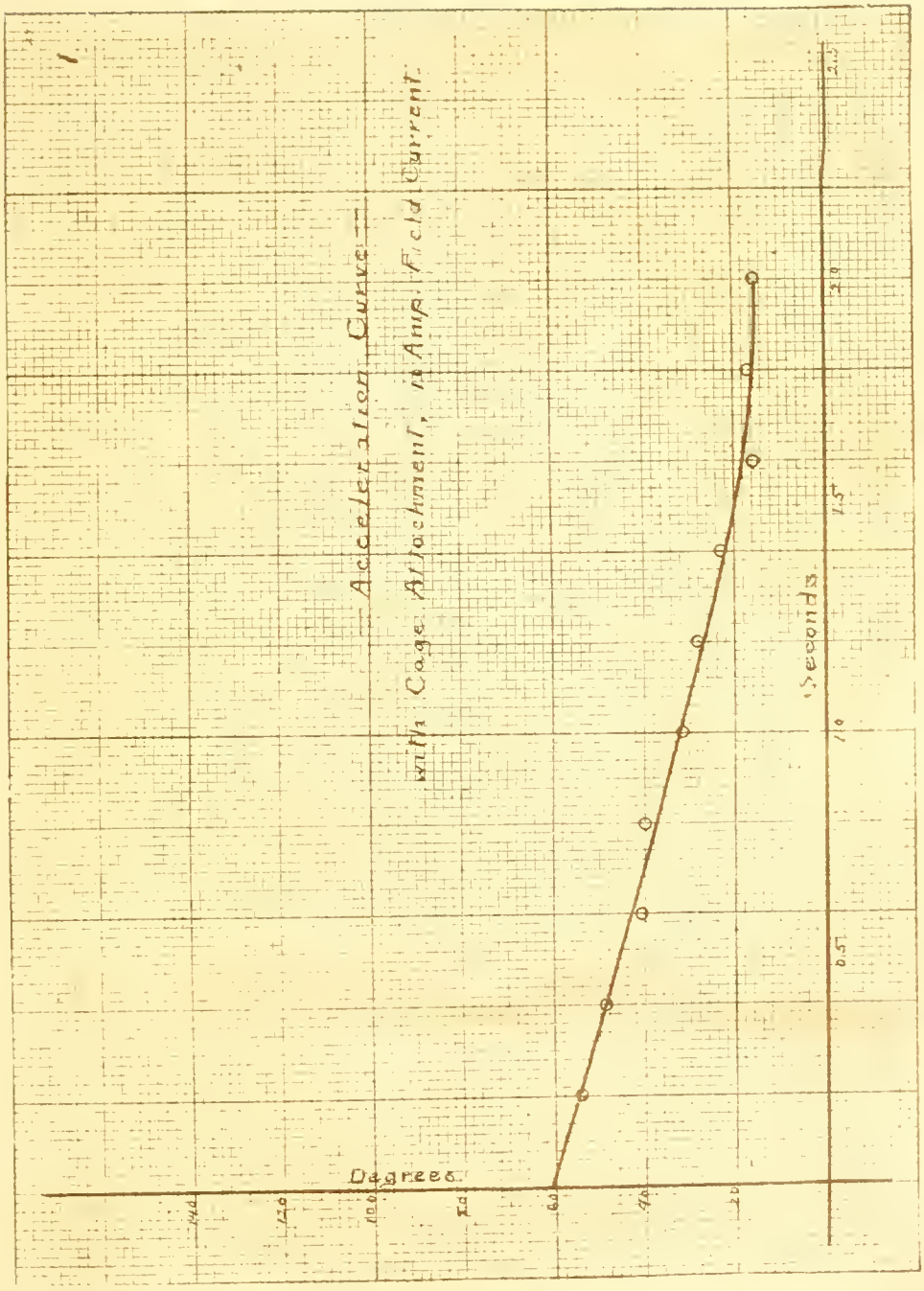


Fig. 1.
— Acceleration Curve —
with Cage Attachment, 11 Amp. Field Current.
Degrees.
Seconds.

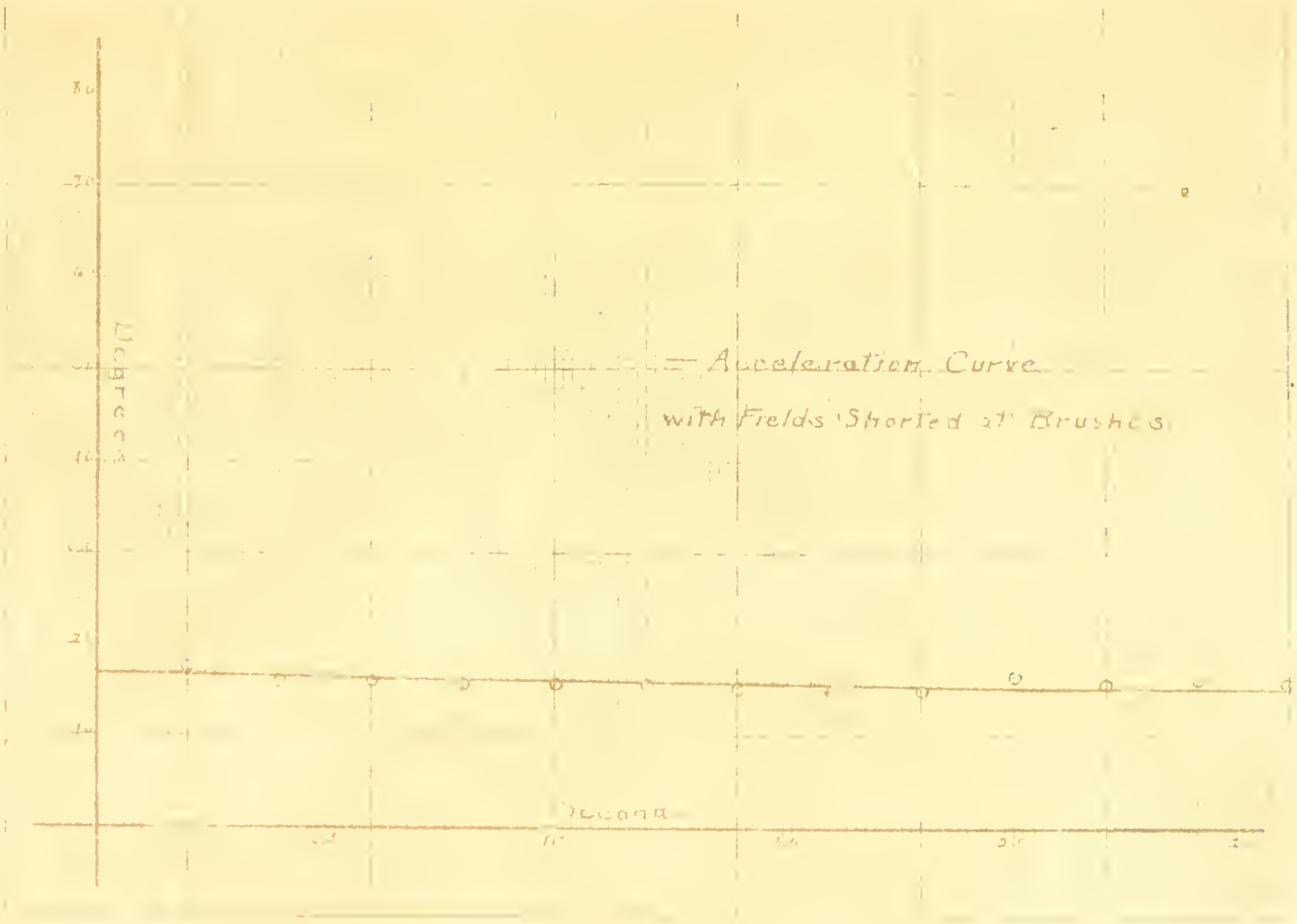
DETERMINATION OF STARTING TORQUE

WITH FIELDS SHORTED AT BRUSHES.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	260		
10	271.0	11.0	
20	299.5	28.5	17.5
30	344.0	44.5	16.0
40	44.5	60.5	16.0
50	121.0	76.5	16.0
60	213.0	92.0	15.5
70	320.5	107.5	15.5
80	83.0	122.5	15.0
90	220.5	137.5	15.0
100	13.0	152.5	15.0
110	182.0	169.0	16.5
120	6.5	184.5	15.5
130	207.0	200.5	16.0
140	63.0	216.0	15.5

Starting acceleration (from curve), ------- 17^{o}

Starting torque,---------- 20.I ft. lbs.


= Acceleration Curve
with Fields Shorted at Brushes
Degrees
Seconds

DETERMINATION OF THE TIME REQUIRED

TO REACH SYNCHRONISM, FIELDS SHORTED INDIVIDUALLY.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	129.0		
10	146.0	17.0	
20	182.0	36.0	19.0
30	238.0	56.0	20.0
40	309.0	71.0	15.0
50	37.0	88.0	17.0
60	141.0	104.0	16.0
70	259.0	118.0	14.0
80	32.0	133.0	15.0
90	179.0	147.0	14.0
100	340. 0	161.0	14.0
110	157.0	177.0	16.0
120	347.0	190.0	13.0
130	192.0	205.0	15.0
140.	53.0	221.0	16.0

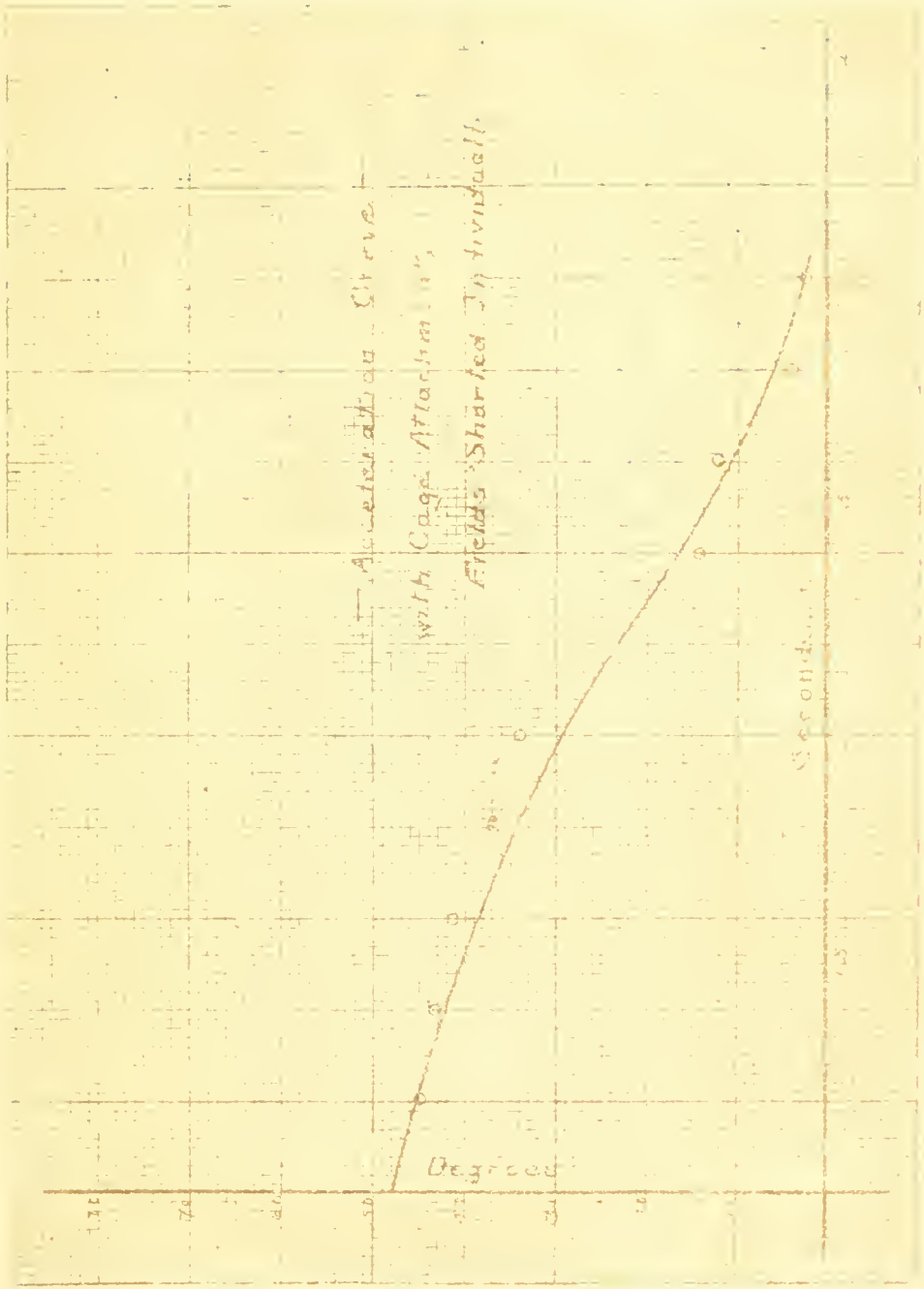
DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, FIELDS SHORTED INDIVIDUALLY.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	149.0		
10	176.0	27.0	
20	248.0	72.0	45.0
30	3.3	115.3	43.3
40	160.0	156.7	41.4
50	353.0	193.0	36.3
60	220.0	227.0	34.0
70	118.5	258.5	31.5
80	31.0	272.5	14.0
90	315.5	284.5	12.0
100	244.0	288.5	4.0
110	175.0	291.0	2.5

Starting acceleration (from curve),--------- 48^{o}

Starting torque, ---------- 56.6 ft. lbs.


Accelerating Curve
with Cage Attachment
Fields Shorted Tinsdall
Seconds
Degrees

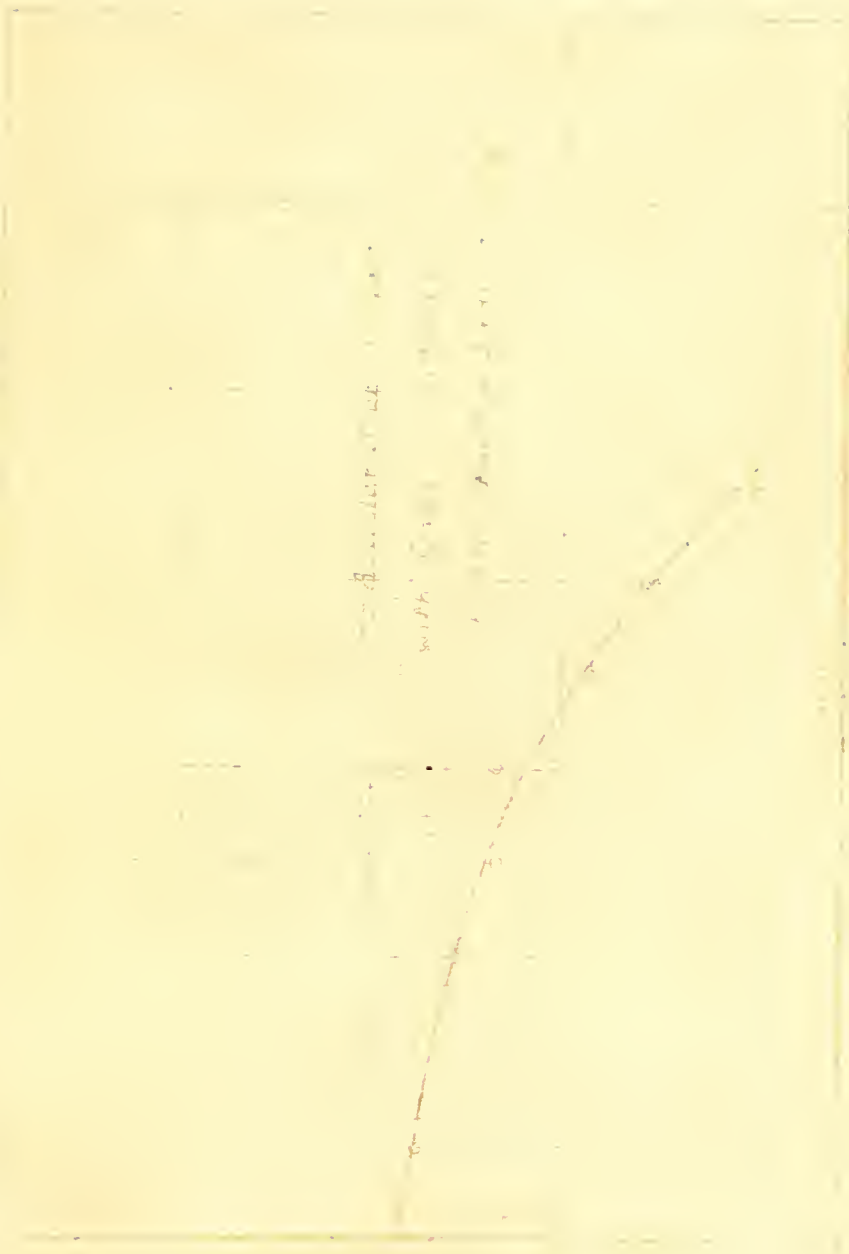
DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, FIELDS SHORTED INDIVIDUALLY.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	175.0		
10	204.5	29.5	
20	279.0	74.5	45.0
30	35.5	116.5	42.0
40	193.0	157.5	41.0
50	26.0	193.0	36.5
60	256.0	230.0	37.0
70	153.0	257.0	27.0
80	71.0	278.0	21.0
90	359.0	288.0	10.0

Starting acceleration (from curve),---------- 47^{o}

Starting torque, ---------- 55.5 ft. lbs.



DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, AND FIELDS SHORTED INDIVIDUALLY.

VIBRATIONS.	ANGLE.	ANGULAR. VELOCITY.	ANGULAR. ACCELERATION.
0	159.0		
10	184.0	25.0	
20	248.0	64.0	39.0
30	346.0	98.0	34.0
40	114.0	128.0	30.0
50	268.0	154.0	26.0
60	90.0	182.0	28.0
70	294.0	204.0	22.0
80	164.0	230.0	26.0
90	55.0	251.0	21.0
100	325.0	270.0	19.0
110	251.0	286.0	16.0

Starting acceleration (from curve),------- 45°

Starting torque, ---------- 55.1 ft.lbs.

Acceleration Curve
with Cage Attachment
Fig 26 Shorted Individually
Starting Angular Position 0°
degrees
second
1.0
2.0

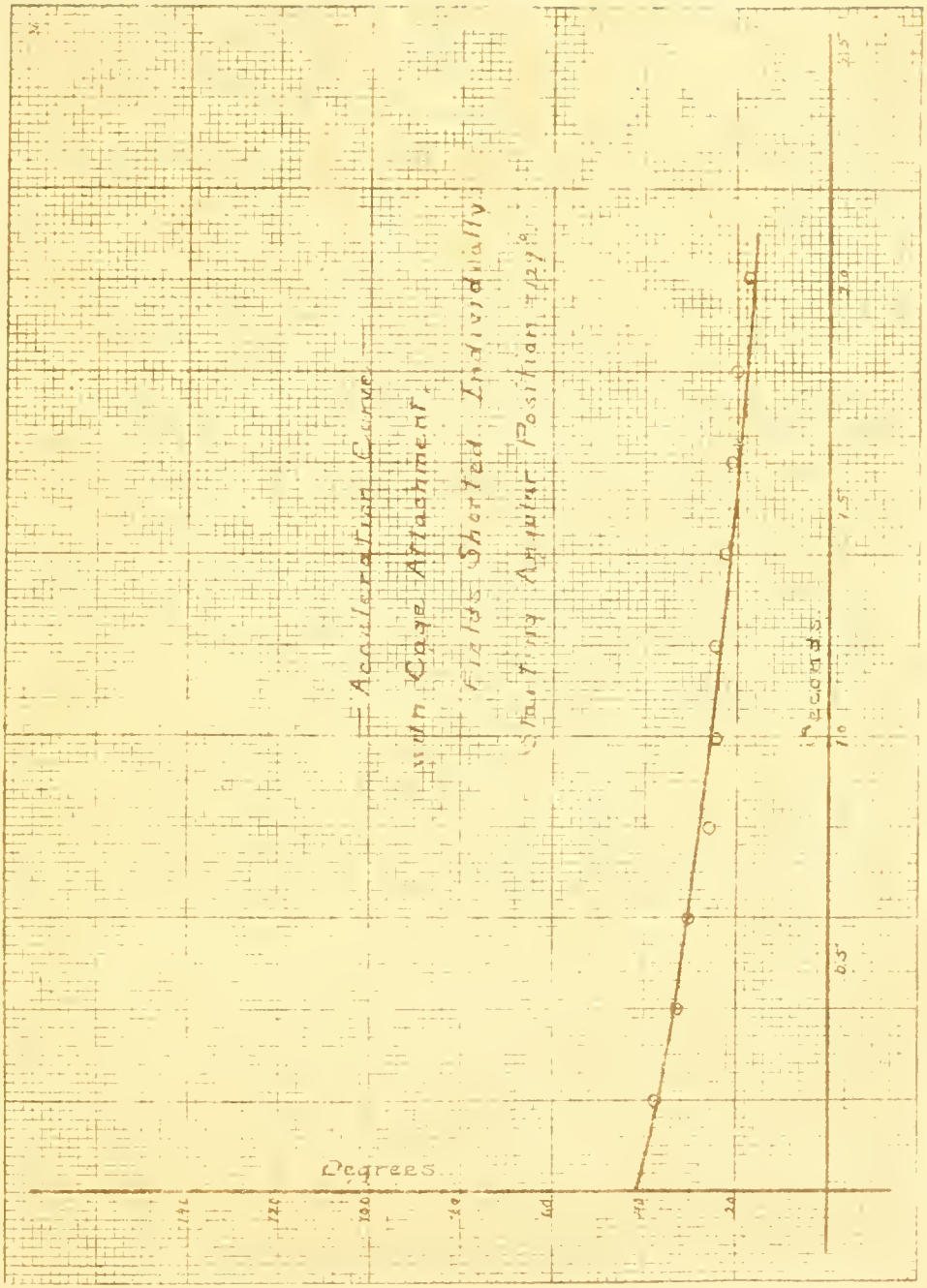
DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, AND FIELDS SHORTED INDIVIDUALLY.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0 0	129.0		
10	157.0	28.0	
20	223.0	66.0	38.0
30	322.0	99.0	33.0
40	91.0	129.0	30.0
50	246.0	155.0	26.0
60	65.0	179.0	24.0
70	269.0	204.0	25.0
80	135.0	226.0	22.0
90	22.0	247.0	21.0
100	289.0	267.0	20.0
110	215.0	284.0	17.0

Starting acceleration (from curve),------- 42^{0}

Starting torque, ---------- 49.5 ft.lbs


Acceleration Curve
with Cage Attachment
Fitted Shorted Individually
Shunt Field Armature Position 7/24
Degrees
Seconds

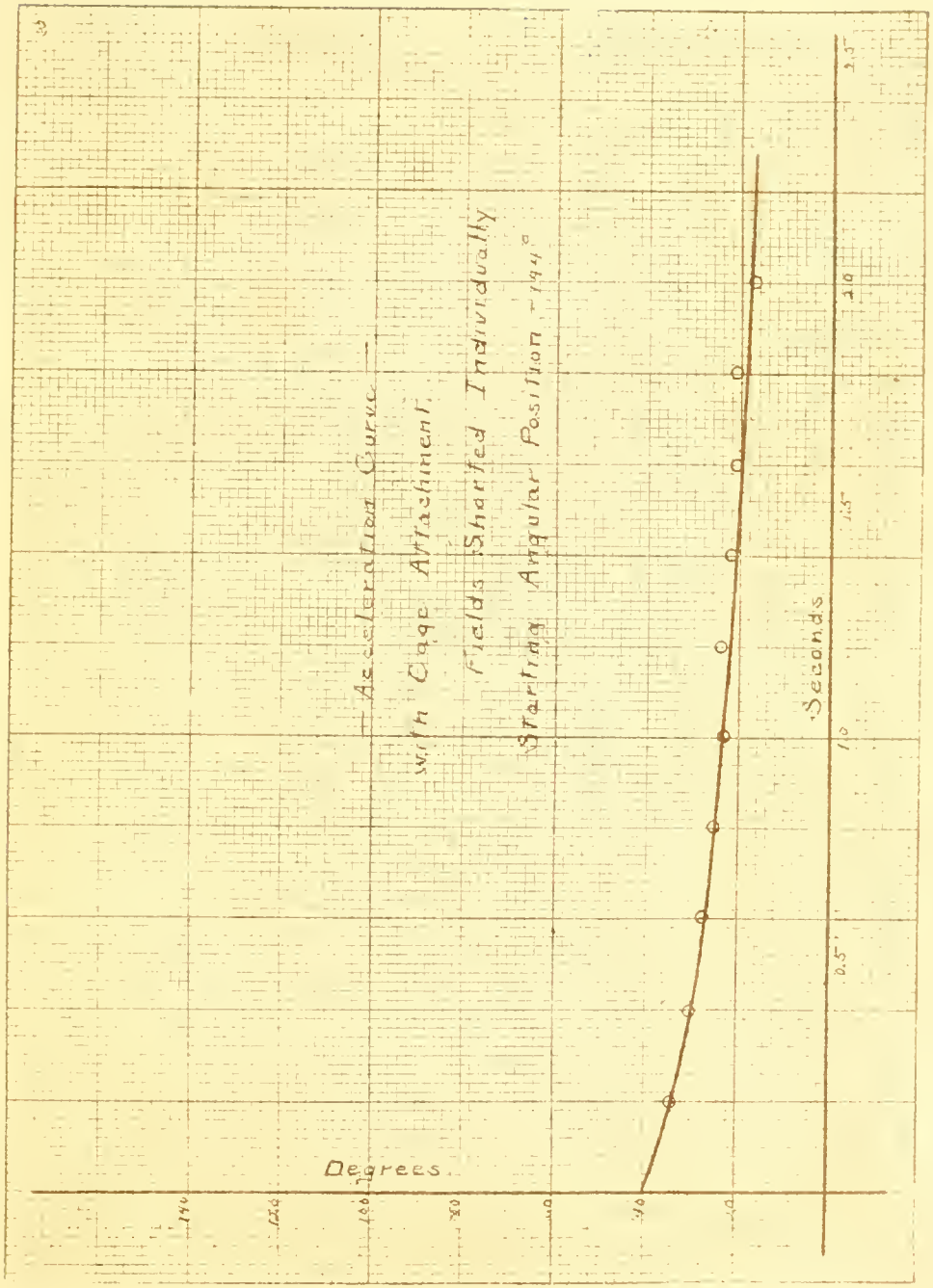
DETERMINATION OF STARTING TORQUE

WITH CAGE ATTACHMENT, AND FIELDS SHORTED INDIVIDUALLY.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	144.0		
10	175.0	29.0	
20	256.0	63.0	34.0
30	329.0	93.0	30.0
40	90.0	121.0	28.0
50	236.0	146.0	25.0
60	45.0	169.0	23.0
70	238.0	193.0	24.0
80	92.0	214.0	21.0
90	328.0	236.0	22.0
100	225.0	257.0	21.0
110	139.0	274.0	17.0

Starting acceleration (from curve), ------ 40°

Starting torque, ---------- 47.2 ft.lbs.


Acceleration Curve
with Cage Attachment.
Fields Sharfed Individually
Starting Angular Position - 144°
Degrees.
Seconds.
140
120
100
80
60
40
0.5"
1.0"
1.5"
2.0"
2.5"

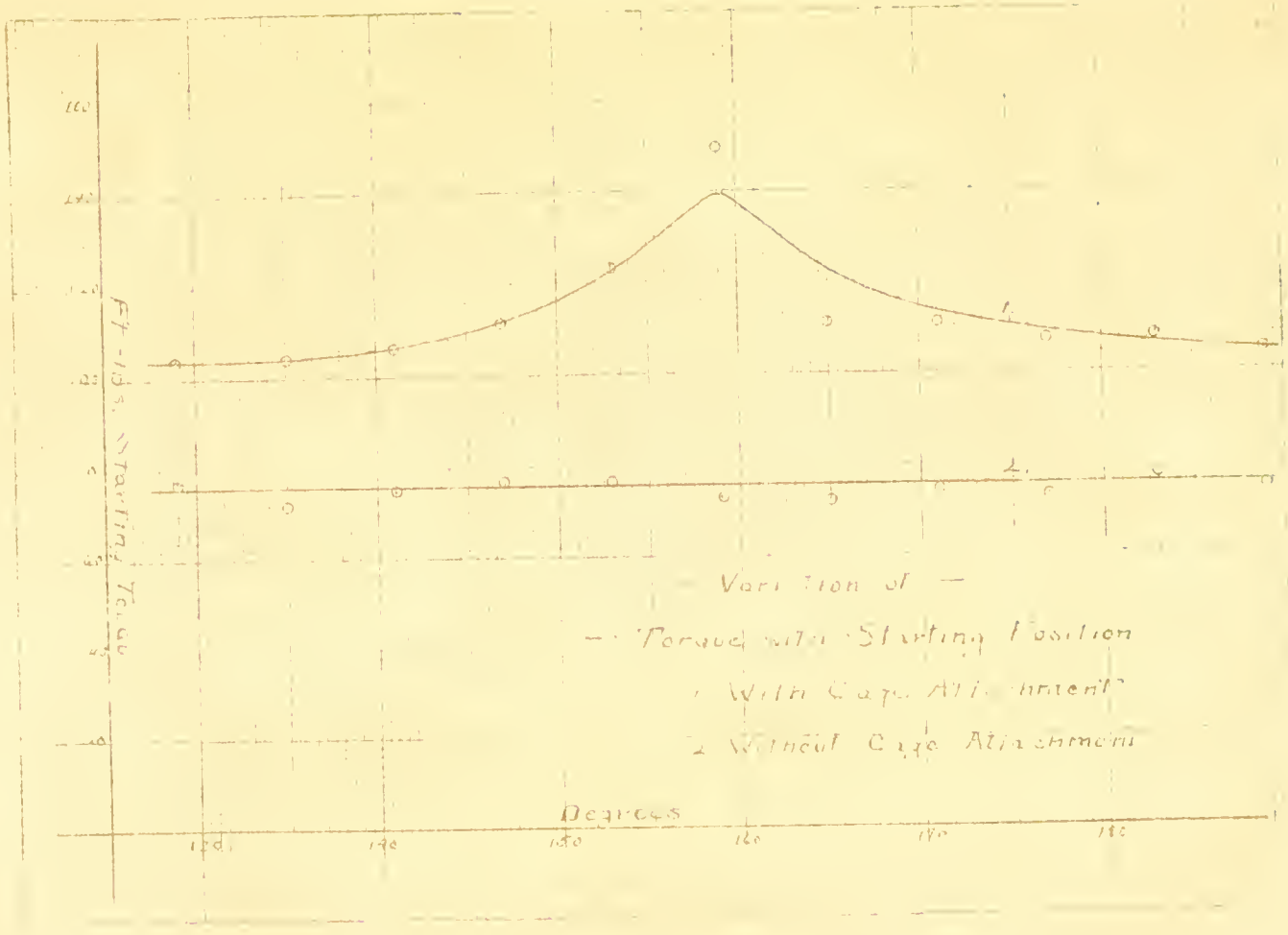
THE EFFECT OF DIFFERENT RELATIVE POSITIONS.

The next set of runs was undertaken to determine the effect upon the starting torque of different relative positions of rotor to stator. From the results obtained, without the cage, the relative position makes no perceptable difference. With the cage, however, considerable variation was noted, and that there is a definite maximum and minimum value in every 180 magnetic degrees. Due to the inaccessibility of the armature windings, it was impossible to determine the relative position of rotor to stator windings at which this maximum occured. The curves plotted from the results of these series of runs show the increase of torque due to the cage attachment.

VARIATION OF TORQUE WITH STARTING POSITION.

ANGULAR POSITION.	TORQUE WITH CAGE.	TORQUE WITHOUT CAGE.
129°	104.0	76.6
135	104.0	72.0
141	106.0	74.3
147	111.0	76.6
153	124.0	76.6
159	150.0	73.1
165	111.0	72.0
171	111.0	74.3
177	107.3	73.1
183	108.6	77.8
189	104.0	74.3
195	107.3	75.5

One mechanical degree equals 3 electrical degrees.

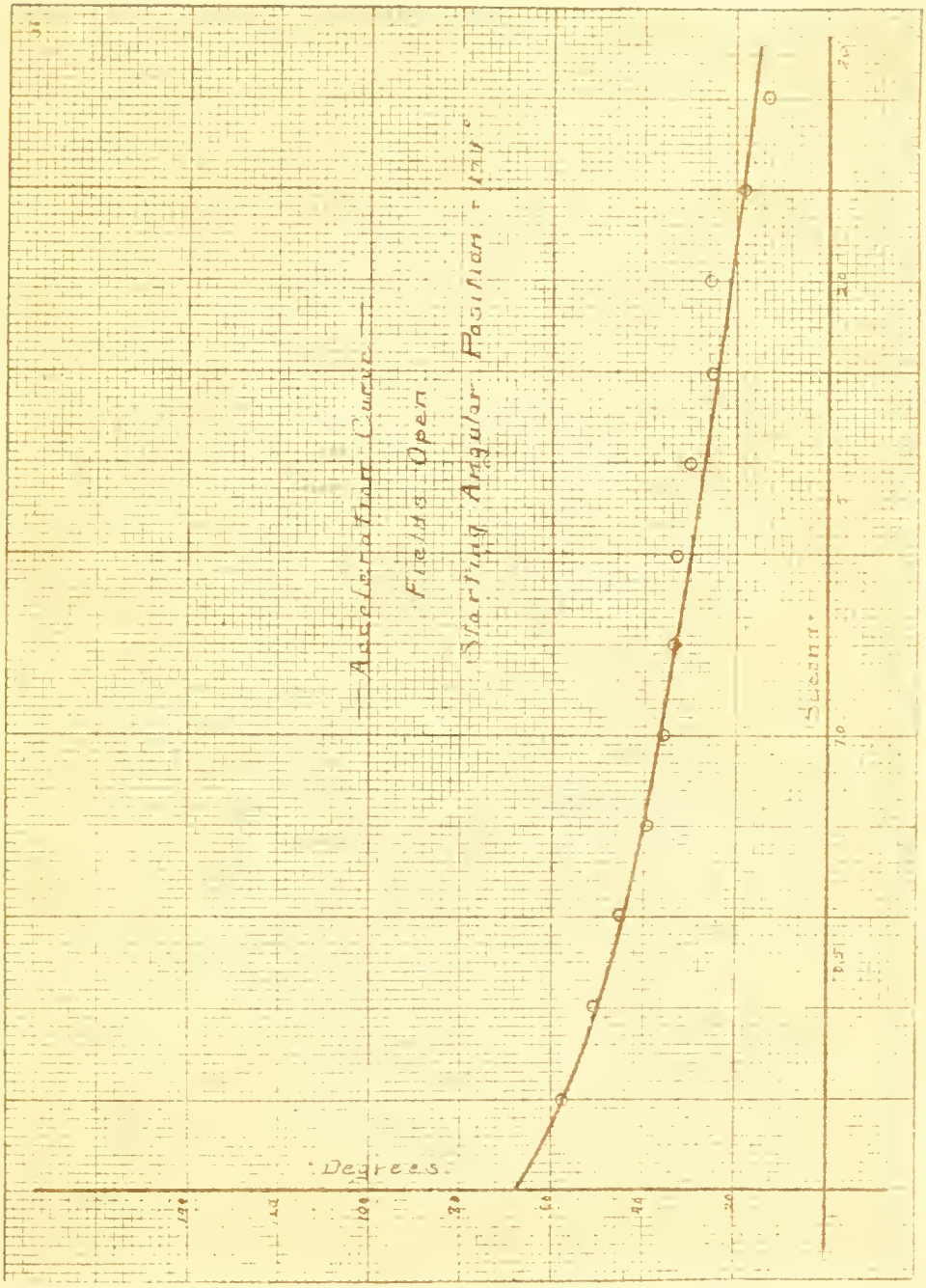

Ft.-lbs. Starting Torque
Variation of —
— Torque with Starting Position
With Cage Attachment
Without Cage Attachment
Degrees

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 129°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	129.0		
10	165.0	36.0	
20	259.0	94.0	58.8
30	43.0	144.0	50.0
40	233.0	190.0	46.0
50	102.0	229.0	39.0
60	7.0	265.0	36.0
70	306.0	299.0	34.0
80	278.0	332.0	33.0
90	280.0	362.0	30.0
100	301.0	387.0	25.0
110	0.0	413.0	26.0
120	71.0	431.0	18.0
130.0	165.0	454.0	15.0

Starting acceleration (from curve), ------ 65°

Starting torque, ---------- 76.6 ft. lbs.


Accelerator Curve
Throttle Open
Starting Angular Position 120°
Degrees.

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 135°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	135.0		
10	168.0	33.0	
20	255.0	87.0	54.0
30	30.0	135.0	48.0
40	207.0	177.0	42.0
50	63.0	216.0	39.0
60	314.0	251.0	35.0
70	238.0	284.0	33.0
80	193.0	315.0	31.0
90	176.0	343.0	28.0
100	189.0	373.0	30.0
110	226.0	397.0	24.0
120	286.0	420.0	23.0
130	7.0	441.0	21.0

Starting acceleration (from curve), ------ 61°

Starting torque, ---------- 72.0 ft.lbs.

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 141°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	141.0		
10	182.0	41.0	
20	279.0	97.0	56.0
30	65.0	146.0	49.0
40	255.0	190.0	44.0
50	123.0	228.0	38.0
60	27.0	264.0	36.0
70	325.0	298.0	34.0
80	294.0	329.0	31.0
90	294.0	360.0	31.0
100	319.0	385.0	25.0
110	10.0	411.0	26.0
120	81.0	431.0	20.0
130	174.0	453.0	12.0

Starting acceleration (from curve), ------ 63°

Starting torque,---------- 74.3 ft.lbs.

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 147°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	147.0		
10	185.0	38.0	
20	280.0	95.0	57.0
30	64.0	144.0	49.0
40	251.0	187.0	43.0
50	116.0	225.0	38.0
60	17.0	261.0	36.0
70	311.0	294.0	33.0
80	279.0	328.0	34.0
90	274.0	355.0	27.0
100	296.0	382.0	27.0
110	344.0	408.0	26.0
120	52.0	428.0	20.0
130	141.0	449.0	21.0

Starting acceleration (from curve), ------ 65°

Starting torque, ---------- 76.6 ft.lbs.

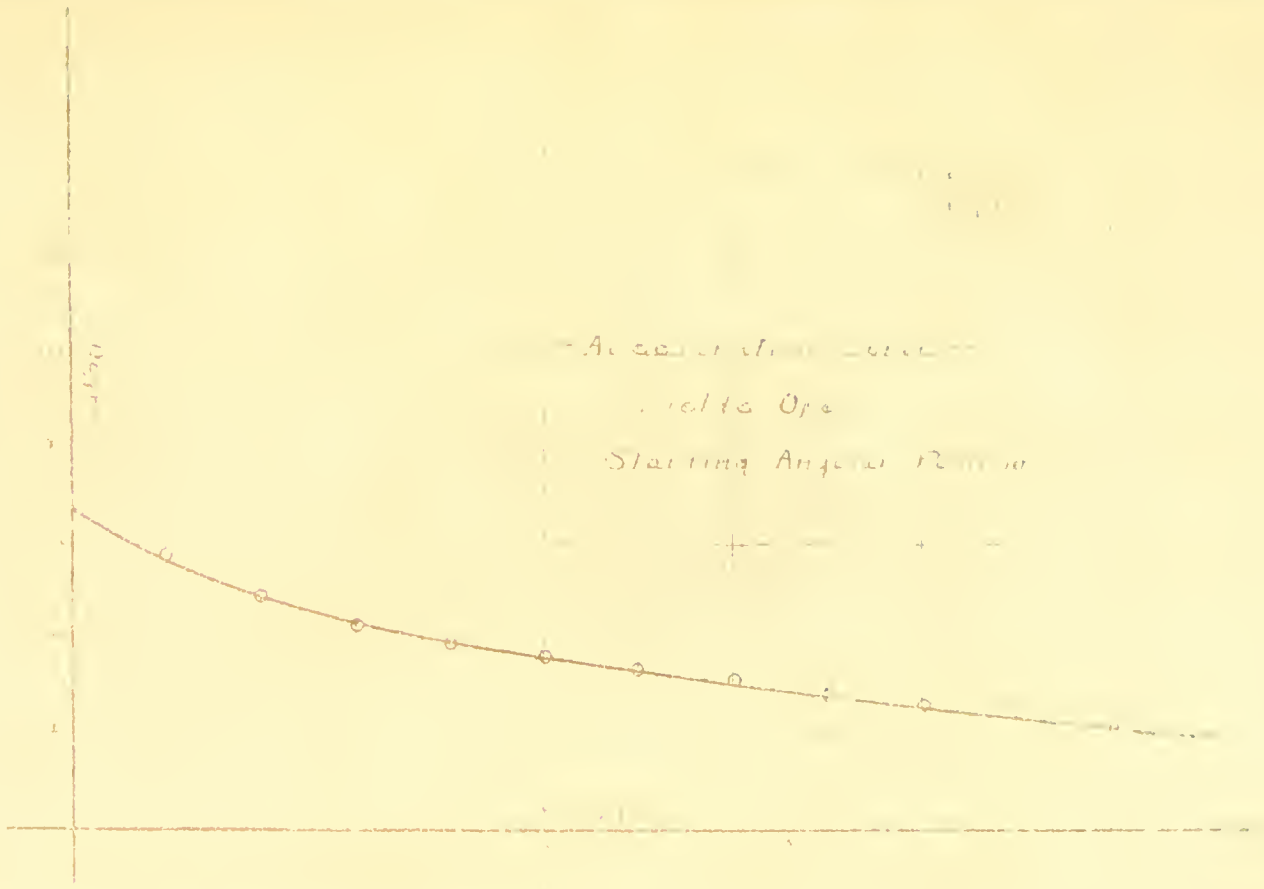
— Acceleration Curve
Fields Open
Starting Angular Position .147"

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 153°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	153.0		
10	187.0	34.0	
20	279.0	92.0	58.0
30	60.0	141.0	49.0
40	244.0	184.0	43.0
50	107.0	223.0	39.0
60	6.0	259.0	36.0
70	299.0	293.0	34.0
80	264.0	325.0	32.0
90	259.0	355.0	30.0
100	280.0	381.0	26.0
110	327.0	407.0	26.0
120	360.0	429.0	22.0

Starting acceleration (from curve), --------- 65°

Starting torque, ---------- 76.6 ft.lbs.

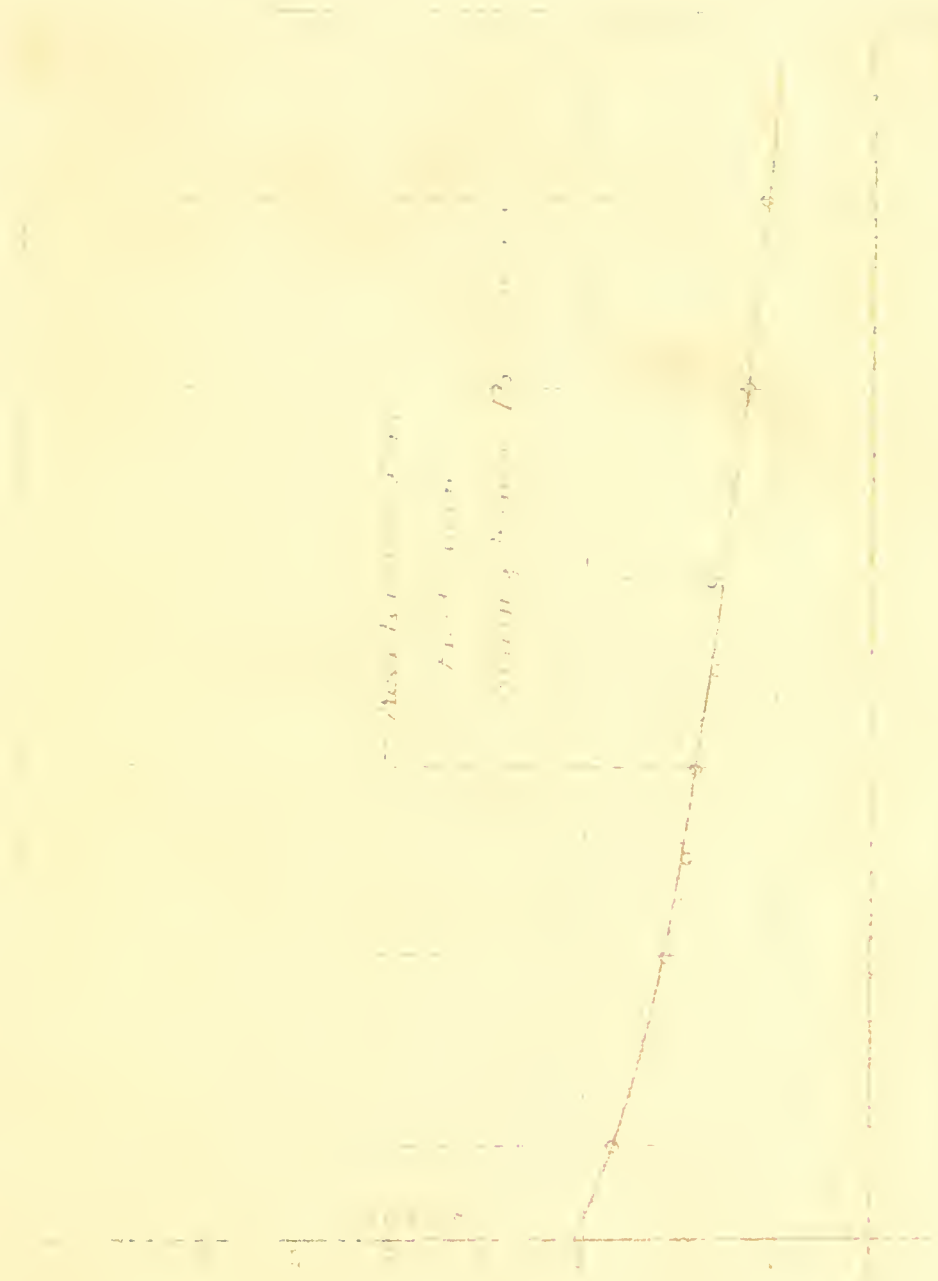


DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 159°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	159.0		
10	194.0	35.0	
20	285.0	91.0	56.0
30	66.0	141.0	50.0
40	250.0	184.0	43.0
50	112.0	222.0	38.0
60	11.0	259.0	37.0
70	302.0	291.0	32.0
80	267.0	325.0	34.0
90	261.0	354.0	29.0
100	281.0	380.0	26.0
110	327.0	406.0	26.0
120	35.0	428.0	22.0
130	123.0	448.0	20.0

Starting acceleration (from curve), ------ 62°

Starting torque, ---------- 73.1 ft.lbs.



DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 165°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	165.0		
10	203.0	38.0	
20	295.0	92.0	54.0
30	73.0	138.0	46.0
40	252.0	179.0	41.0
50	106.0	214.0	35.0
60	353.0	247.0	33.0
70	273.0	280.0	33.0
80	221.0	308.0	28.0
90	198.0	337.0	29.0
100	203.0	365.0	28.0
110	230.0	387.0	22.0
120	282.0	412.0	25.0
130	358.0	456.0	24.0

Starting acceleration (from curve), ------ 61°

Starting torque, ---------- 72.0 ft.lbs.

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 171°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	171.0		
10	211.0	40.0	
20	306.0	95.0	55.0
30.	88.0	142.0	47.0
40	271.0	183.0	41.0
50	130.0	219.0	36.0
60	24.0	254.0	35.0
70	310.0	286.0	32.0
80	266.0	316.0	30.0
90	252.0	346.0	30.0
100	264.0	372.0	26.0
110	302.0	398.0	26.0
120	2.0	420.0	22.0
130	32.0	440.0	20.0

Starting acceleration (from curve), ------ 63°

Starting torque, ---------- 74.3 ft.lbs.

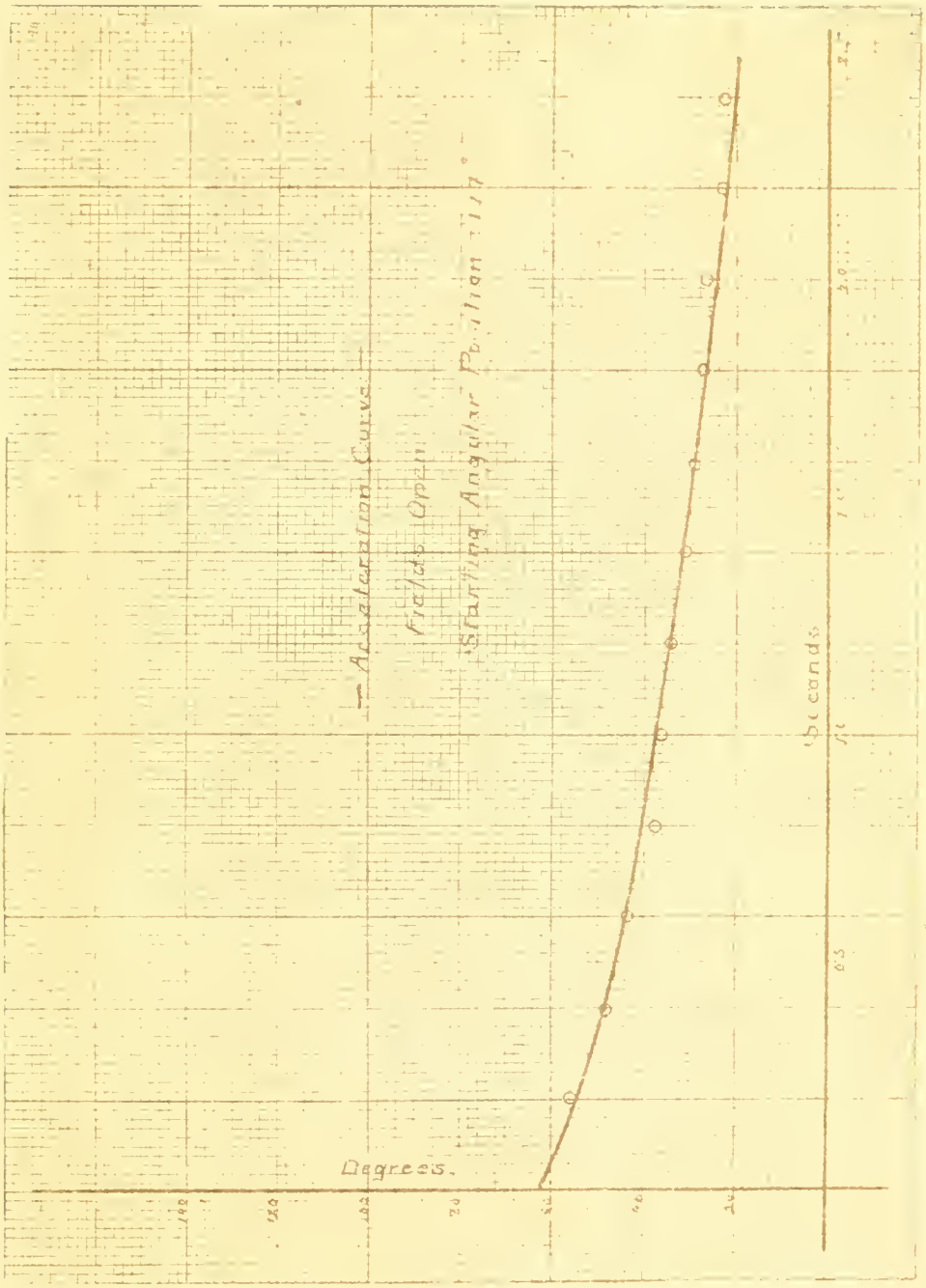
Acceleration Curve
Fields Open
Starting Angular Position
Degrees
Degrees

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 177°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	177.0		
10	208.0	31.0	
20	295.0	87.0	56.0
30	70.0	135.0	48.0
40	248.0	178.0	43.0
50	103.0	215.0	37.0
60	353.0	250.0	35.0
70	277.0	284.0	34.0
80	232.0	315.0	31.0
90	216.0	344.0	29.0
100	228.0	372.0	28.0
110	267.0	399.0	27.0
120	329.0	422.0	23.0
130	53.0	444.0	22.0

Starting acceleration (from curve), ------ 62°

Starting torque, ---------- 73.1 ft.lbs.


Acceleration Curve
Fr/db Opt.
Starting Angular Position
Degrees.
Seconds

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 183°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	183		
10	217.0	34.0	
20	307.0	90.0	56.0
30	83.0	136.0	46.0
40	260.0	177.0	41.0
50	114.0	214.0	37.0
60	2.0	248.0	34.0
70	283.0	281.0	33.0
80	233.0	310.0	29.0
90	213.0	340.0	30.0
100	219.0	366.0	26.0
110	251.0	392.0	26.0
120	307.0	416.0	24.0

Starting acceleration from curve, --------- 66°

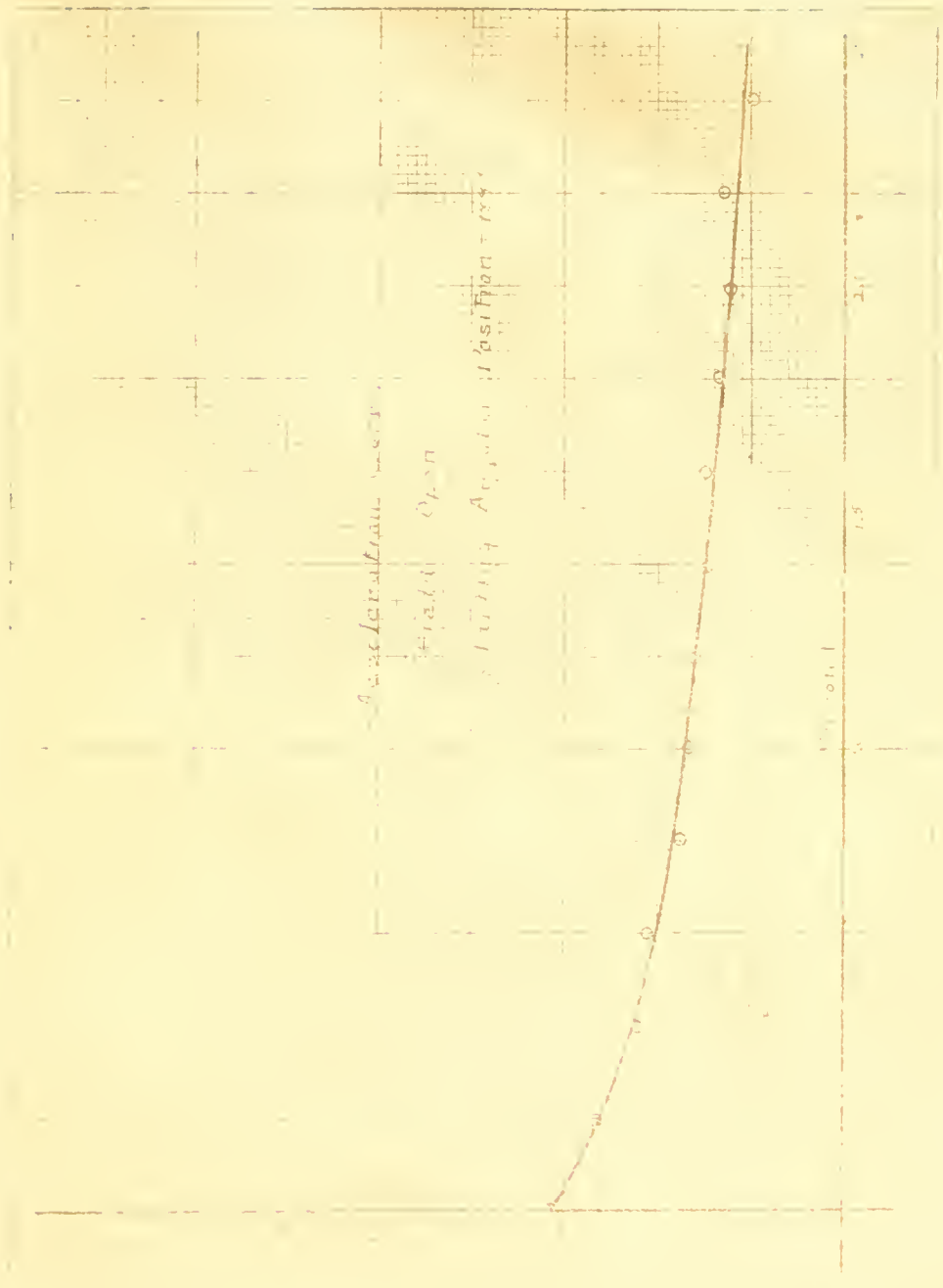
Starting torque, ------------------------- 77.8 ft.lbs.

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 189°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	189.0		
10	227.0	38.0	
20	318.0	91.0	53.0
30	93.0	135.0	44.0
40	270.0	177.0	42.0
50	122.0	212.0	35.0
60	7.0	245.0	33.0
70	284.0	277.0	32.0
80	230.0	306.0	29.0
90	205.0	335.0	29.0
100	207.0	362.0	27.0
110	233.0	386.0	24.0
120	285.0	412.0	26.0
130	357.0	432.0	20.0

Starting acceleration from curve, -------- 63°

Starting torque, ---------- 74.3 ft.lbs.

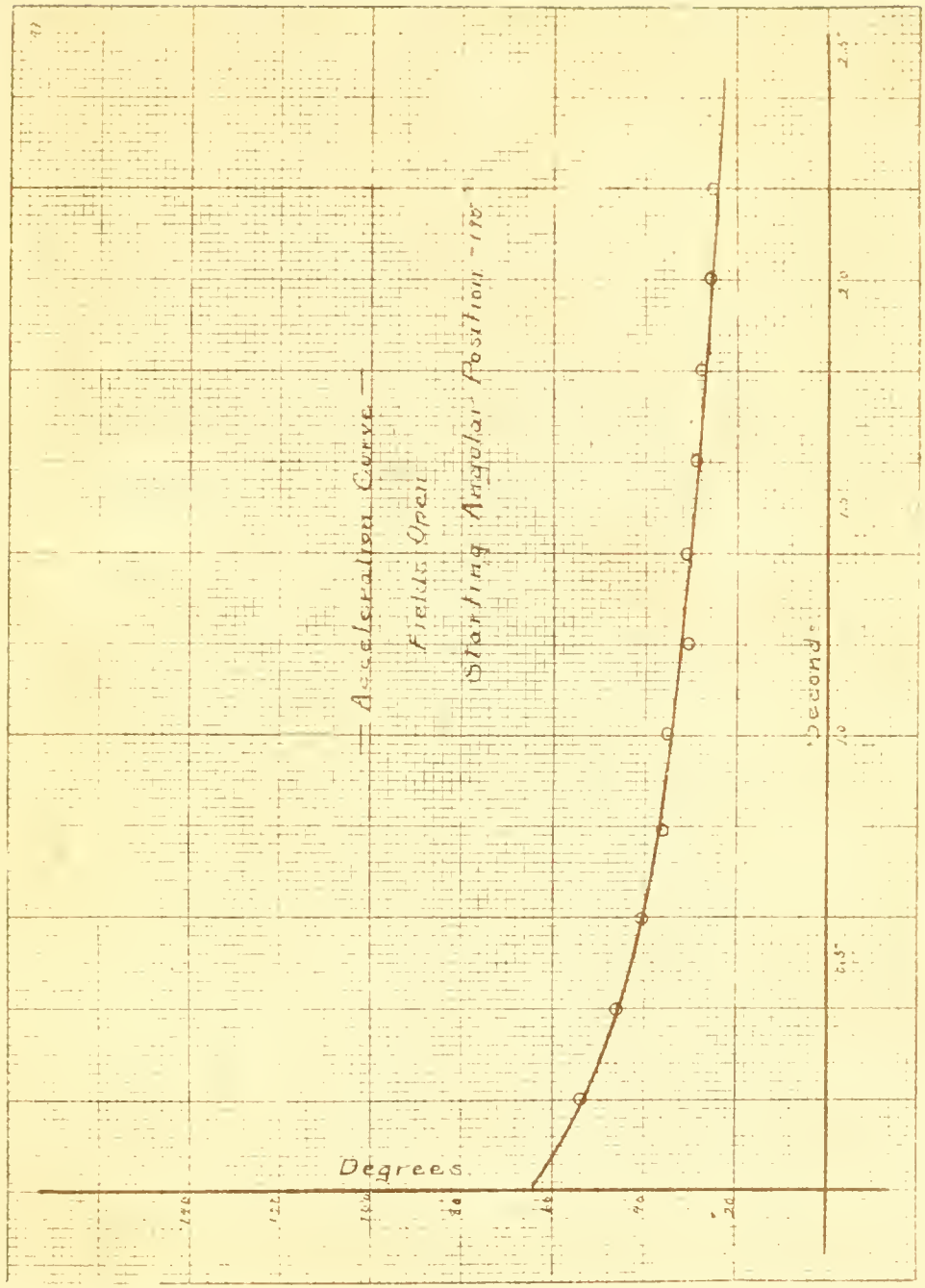


DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, STARTING ANGLE 195°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	195.0		
10	222.0	27.0	
20	303.0	81.0	54.0
30	70.0	127.0	46.0
40	238.0	168.0	41.0
50	82.0	204.0	36.0
60	321.0	239.0	35.0
70	230.0	269.0	30.0
80	170.0	300.0	31.0
90	139.0	329.0	29.0
100	135.0	356.0	27.0
110	157.0	382.0	26.0
120	204.0	407.0	25.0
130.	271.0	427.0	20.0

Starting acceleration (from curve), ------ 64°.

Starting totque, ---------- 75.5 ft.lbs.


Acceleration Curve
Fields Open
Starting Angular Position - 12°
Degrees
Seconds

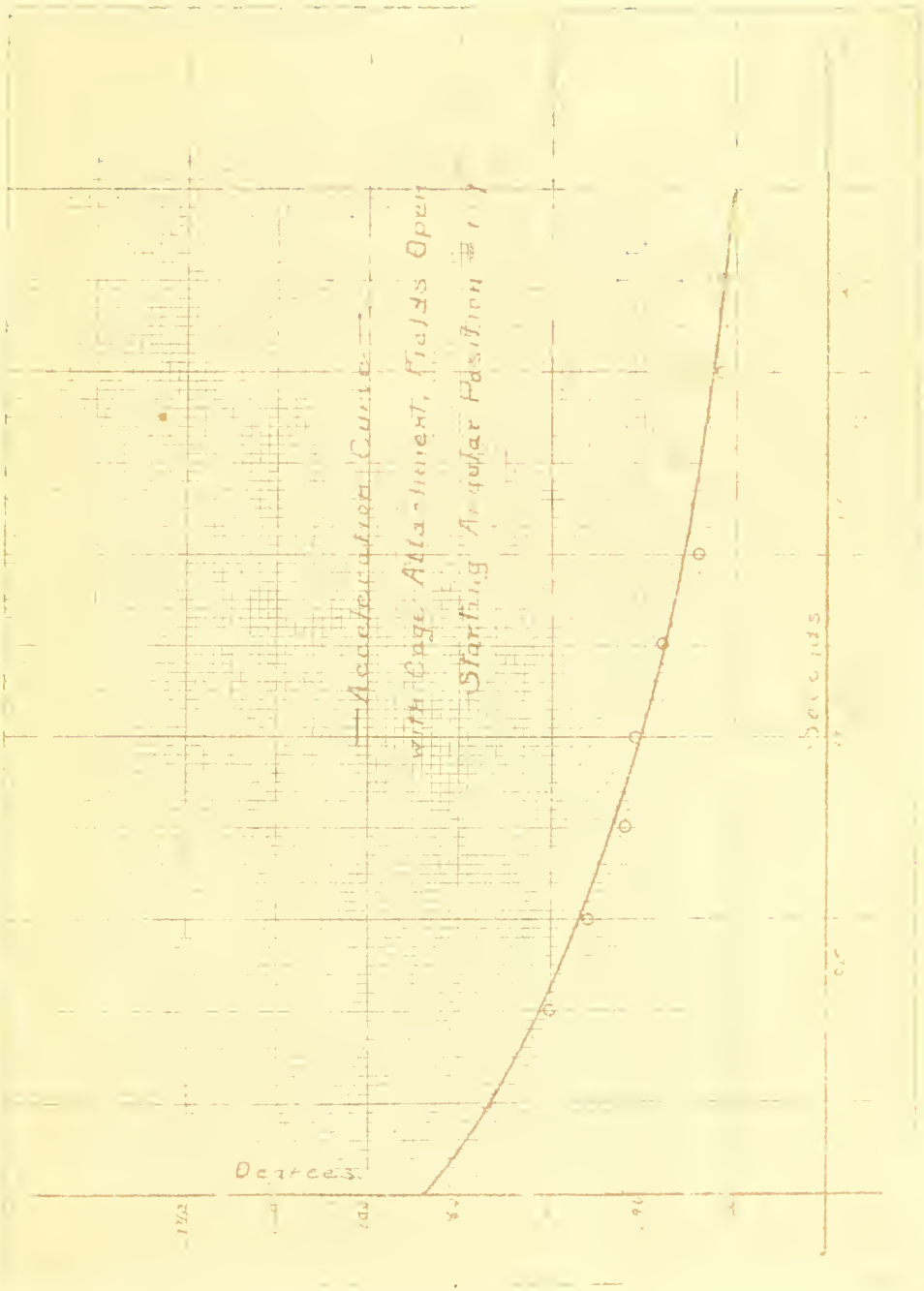
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT.

STARTING ANGLE 129°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ADDELERATION,
0	129.0		
10	176.0	47.0	
20	297.0	121.0	74.0
30	118.0	181.0	60.0
40	351.0	233.0	52.0
50	268.0	277.0	44.0
60	227.0	319.0	42.0
70	222.0	355.0	36.0
80	245.0	383.0	28.0
90	302.0	417.0	34.0
100	22.0	440.0	23.0
110	124.0	462.0	22.0

Starting acceleration (from curve), ------- 88°

Starting torque, ------------------------- 104.0 ft. lbs.

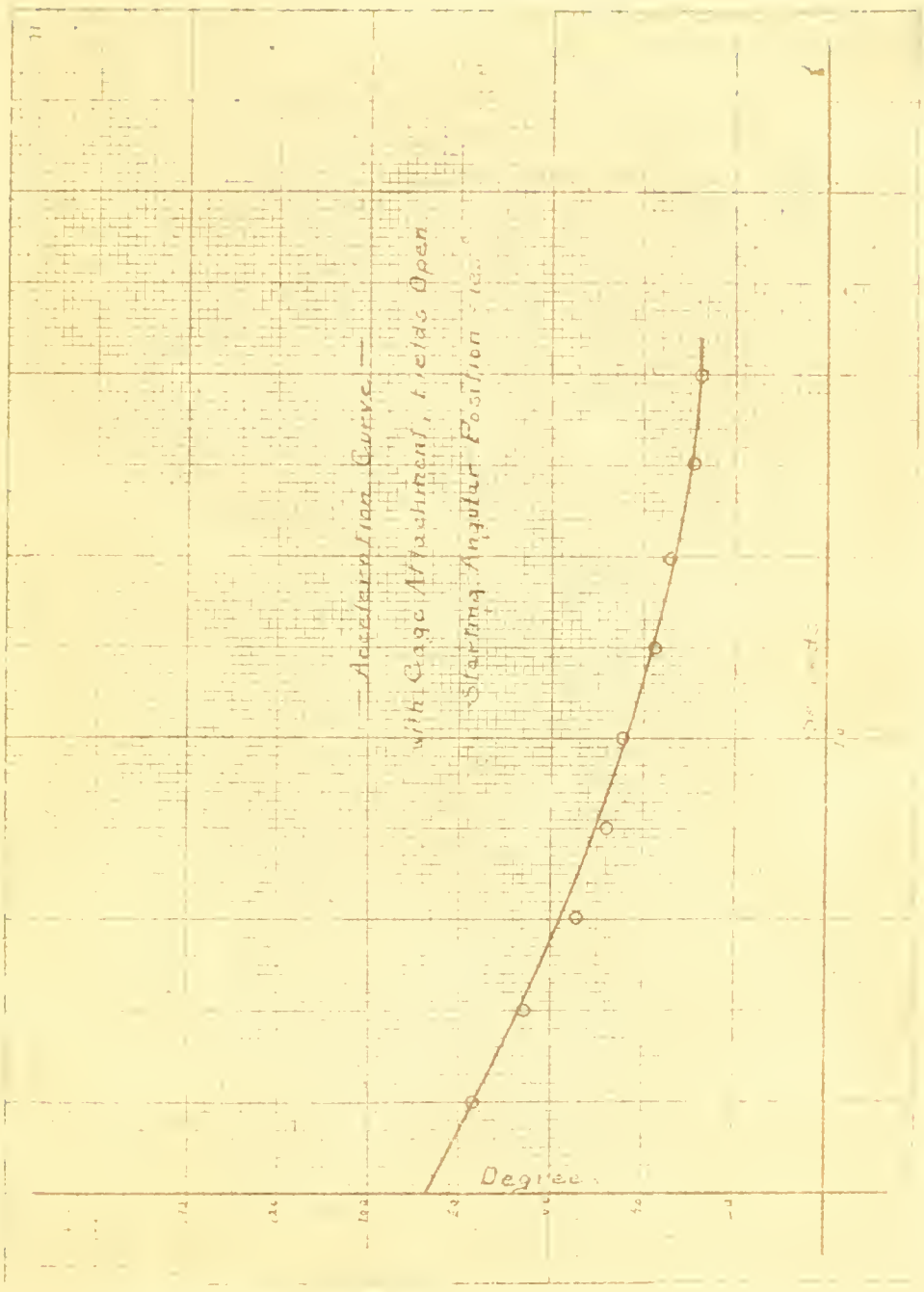

Acceleration Curve
With Gage Attachment, Fields Open
Starting Armature Position #1
Degrees
Seconds

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT. STARTING ANGLE 135°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	135.0		
10	186.0	51.0	
20	314.0	128.0	77.0
30	148.0	194.0	66.0
40	36.0	248.0	54.0
50	332.0	296.0	48.0
60	312.0	340.0	44.0
70	329.0	377.0	37.0
80	20.0	411.0	34.0
90	100.0	440.0	29.0
100	208.0	468.0	28.0
110	332.0	484.0	16.0

Starting acceleration (from curve), ------ 88°

Starting torque,---------- 104.0 ft. lbs.

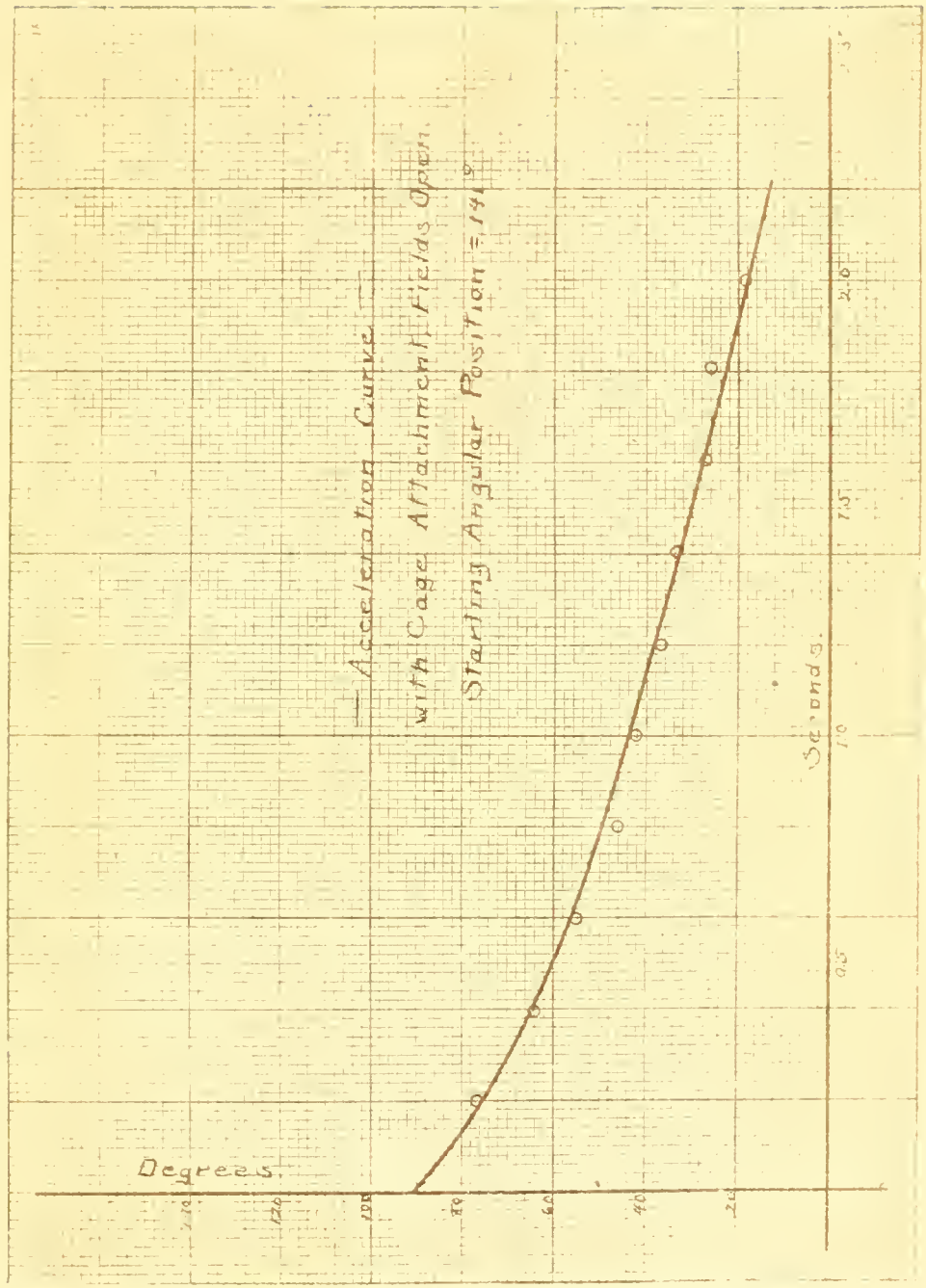

Acceleration Curve
With Cage Attachment, Fields Open
Starting Angular Position
Degree

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT, STARTING ANGLE 141°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	141.0		
10	196.0	55.0	
20	328.0	132.0	77.0
30	164.0	196.0	64.0
40	55.0	251.0	55.0
50	352.0	297.0	46.0
60	331.0	339.0	42.0
70	347.0	376.0	37.0
80	37.0	410.0	34.0
90	114.0	437.0	27.0
100	217.0	463.0	26.0
110	338.0	481.0	18.0

Starting acceleration (from curve), ------ 90°

Starting torque,---------- 106.0 ft. lbs.


Acceleration Curve
With Cage Attachment, Fields Open.
Starting Angular Position = 14°
Degrees.
Seconds.
120
100
80
60
40
20
0.5
1.0
1.5
2.0

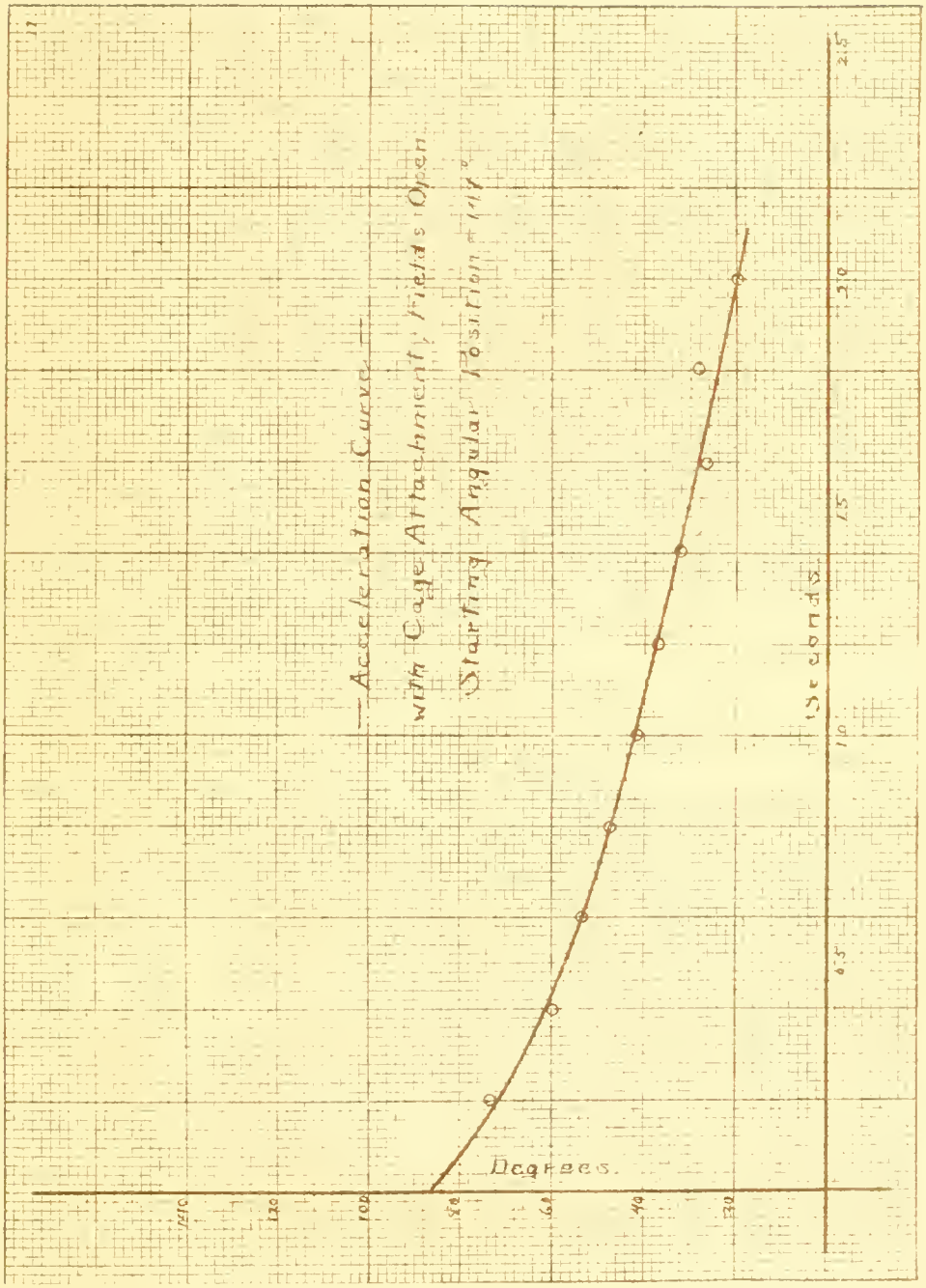
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT.

STARTING ANGLE 147°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	147.0		
10	197.0	50.0	
20	321.0	124.0	74.0
30	149.0	188.0	59.0
40	30.0	241.0	53.0
50	318.0	288.0	47.0
60	287.0	329.0	41.0
70	293.0	366.0	37.0
80	331.0	398.0	32.0
90	35.0	424.0	26.0
100	127.0	452.0	20.0
110	238.0	471.0	19.0

Starting acceleration (from curve), ------ 94°

Starting torque, ---------- 111.0 ft. lbs.


Acceleration Curve
with Cage Attachment, Fields Open
Starting Angular Position +112°
Degrees.
Seconds.

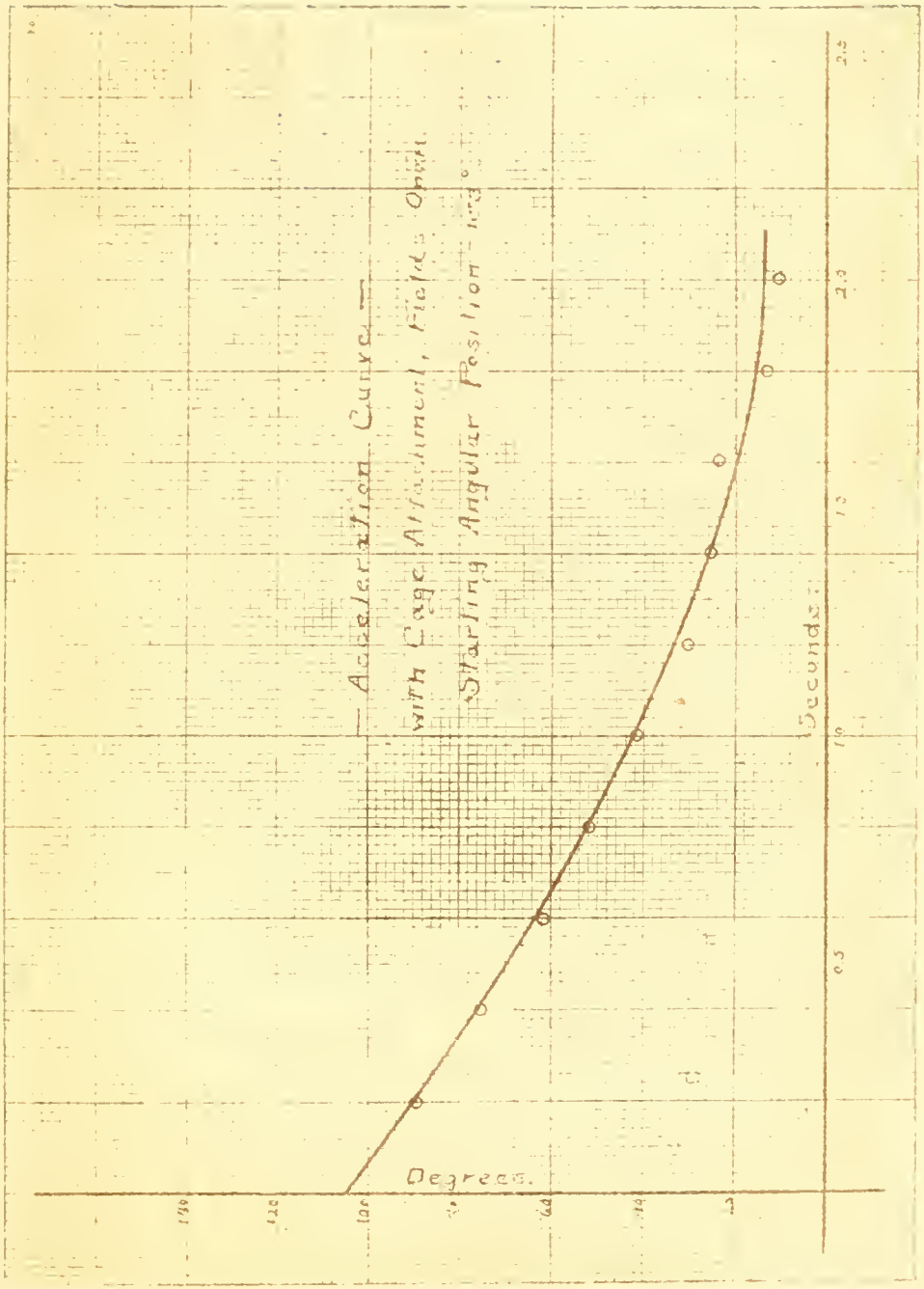
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT.

STARTING ANGLE 153°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	153.0		
10	212.0	59.0	
20	1.0	149.0	90.0
30	225.0	224.0	75.0
40	150.0	285.0	61.0
50	127.0	337.0	52.0
60	145.0	378.0	41.0
70	193.0	408.0	30.0
80	266.0	433.0	25.0
90	3.0	457.0	24.0
100	113.0	470.0	13.0
110	235.0	482.0	12.0

Starting acceleration (from curve), ------ 105°.

Starting torque,---------- 124.0 ft. lbs.


Acceleration Curve
with Cage Attachment, Fields Open.
Starting Angular Position 1.5°
Degrees.
Seconds.

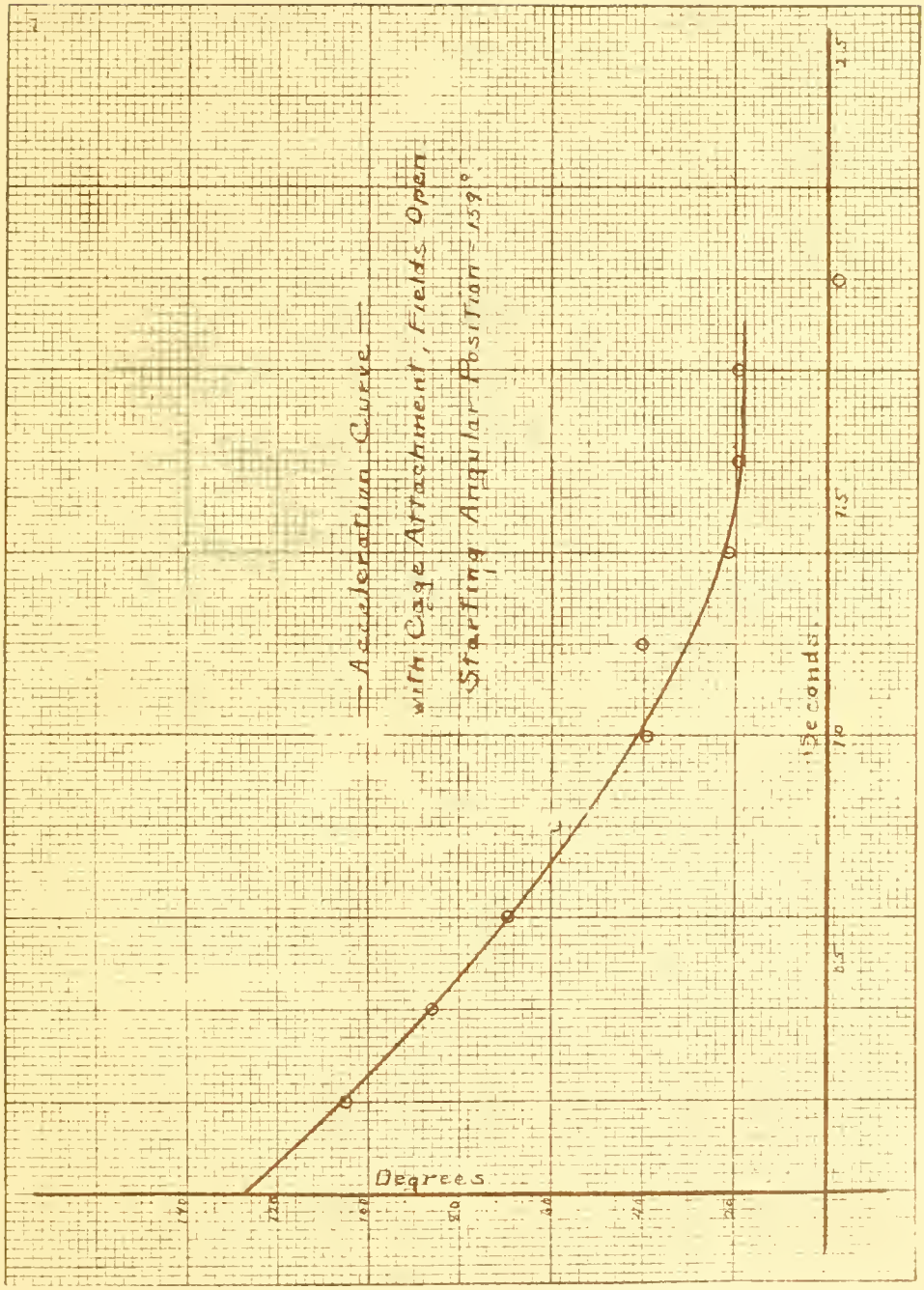
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT.

STARTING ANGLE 159°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	159.0		
10	229.0	70.0	
20	44.0	175.0	105.0
30	305.0	261.0	86.0
40	275.0	330.0	69.0
50	304.0	389.0	59.0
60	12.0	428.0	39.0
70	120.0	468.0	40.0
80	250.0	490.0	22.0
90	40.0	510.0	20.0
100	209.0	529.0	19.0

Starting acceleration from curve, -------- 127°

Starting torque, ---------- 150.0 ft. lbs.

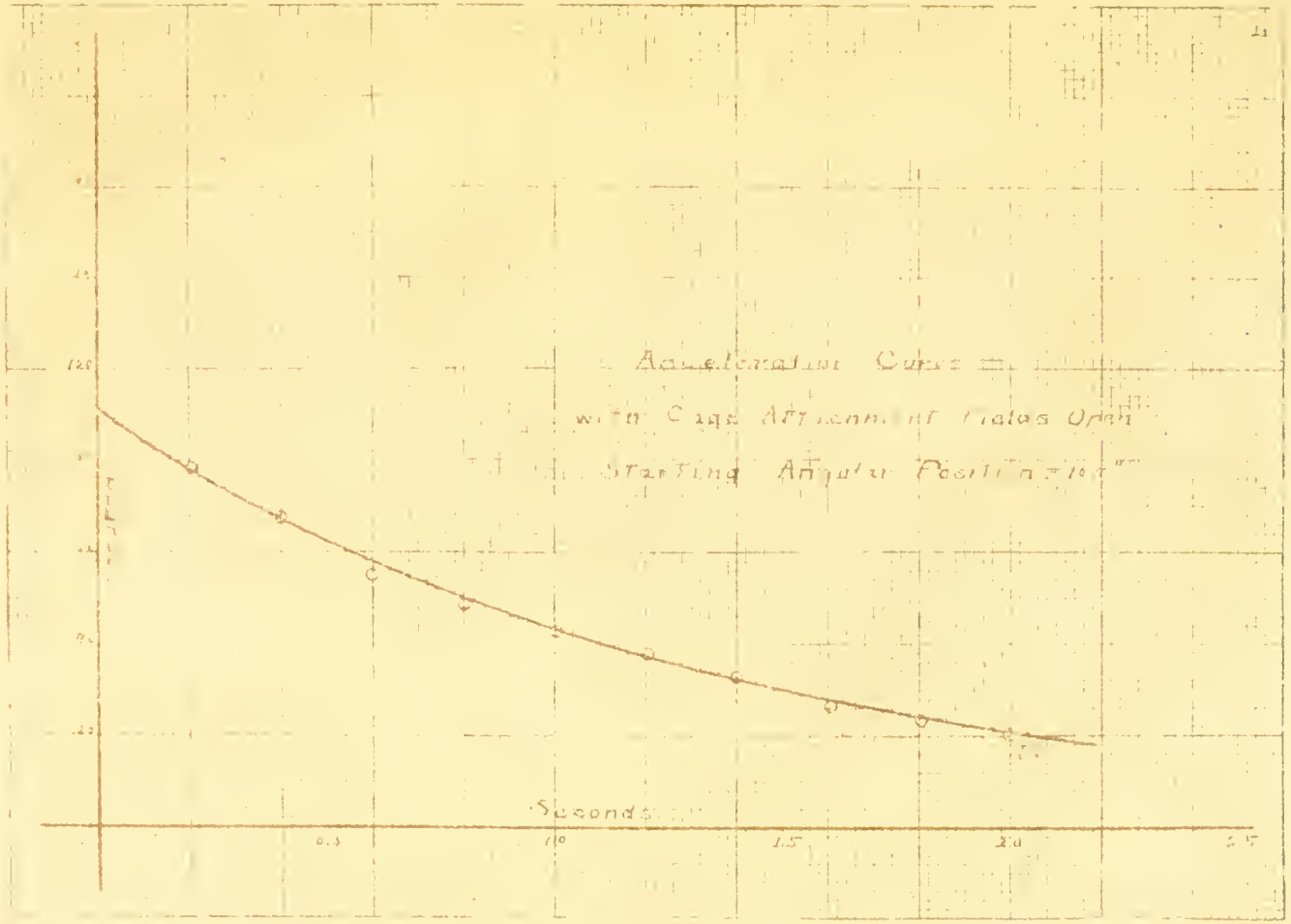

— Acceleration Curve —
with Cage Attachment, Fields Open
Starting Angular Position = 159°
Degrees
Seconds
2.5
1.5
1/10
0.5

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT, STARTING ANGLE 165°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	165.0		
10	215.0	50.0	
20	343.0	128.8	78.0
30	179.0	196.0	68.0
40	69.0	250.0	54.0
50	7.0	298.0	48.0
60	347.0	340.0	42.0
70	5.0	378.0	38.0
80	56.0	411.0	33.0
90	133.0	437.0	26.0
100	233.0	460.0	23.0
110	353.0	480.0	20.0

Starting acceleration (from curve),------- 94°

Starting torque,---------- 111.0 ft.lbs.

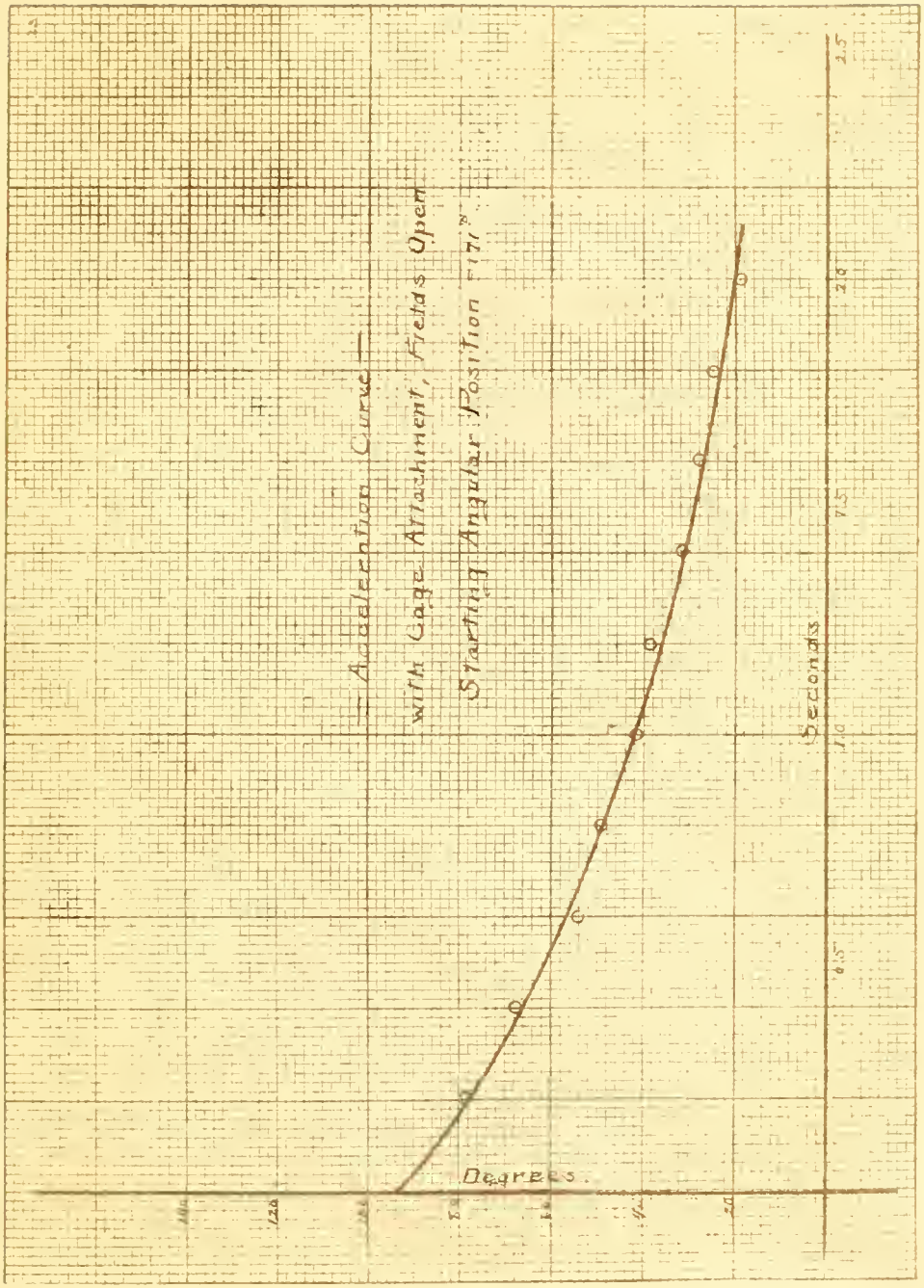

Acceleration Curve
with Cage Attachment Plates Open
Starting Angular Position
Seconds
0.5
1.0
1.5
2.0

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT. STARTING ANGLE 171°.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR. ACCELERATION.
0	171.0		
10	221.0	50.0	
20	349.0	128.0	78.0
30	184.0	195.0	67.0
40	73.0	249.0	54.0
50	11.0	298.0	49.0
60	350.0	339.0	41.0
70	8.0	378.0	39.0
80	57.0	409.0	31.0
90	133.0	436.0	27.0
100	234.0	461.0	25.0
110	354.0	480.0	19.0

Starting acceleration (from curve), ------ 94°

Starting torque, ---------- 111.0 ft.lbs.

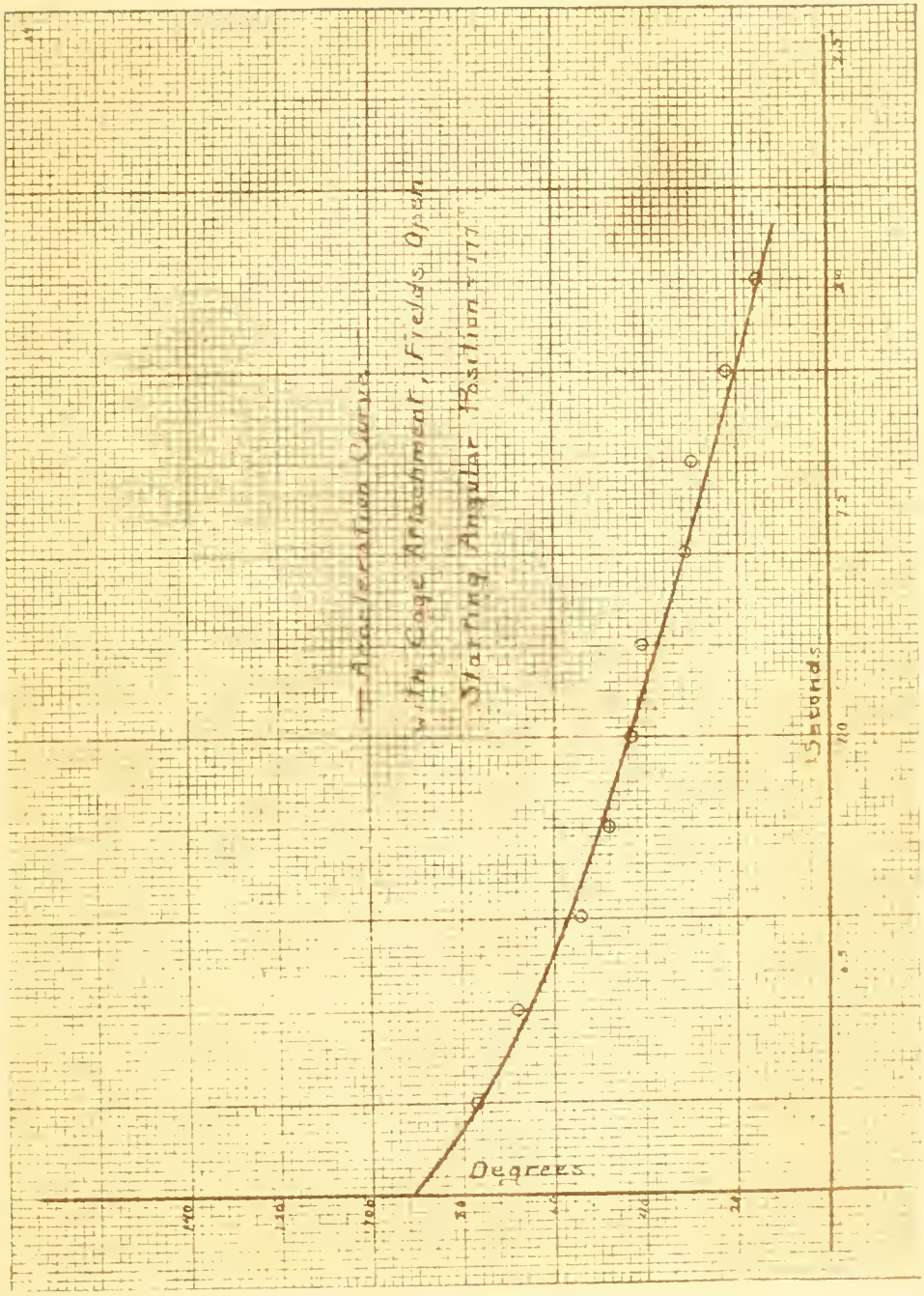

Acceleration Curve
with Cage Attachment, Arms Open
Starting Angular Position -17°
Degrees
Seconds

DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT. STARTING ANGLE 177°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	177.0		
10	224.0	77.0	
20	348.0	124.0	77.0
30	180.0	192.0	68.0
40	66.0	246.0	54.0
50	0.0	294.0	48.0
60	336.0	336.0	42.0
70	353.0	377.0	41.0
80	41.0	408.0	31.0
90	119.0	438.0	30.0
100	219.0	460.0	22.0
110	335.0	476.0	16.0

Starting acceleration (from curve), ------ 91°

Starting torque, ---------- 107.5 ft.lbs.


Acceleration Curves
With Edge Attachment of Fields Open
Starting Angular Positions 177°
Degrees
Seconds

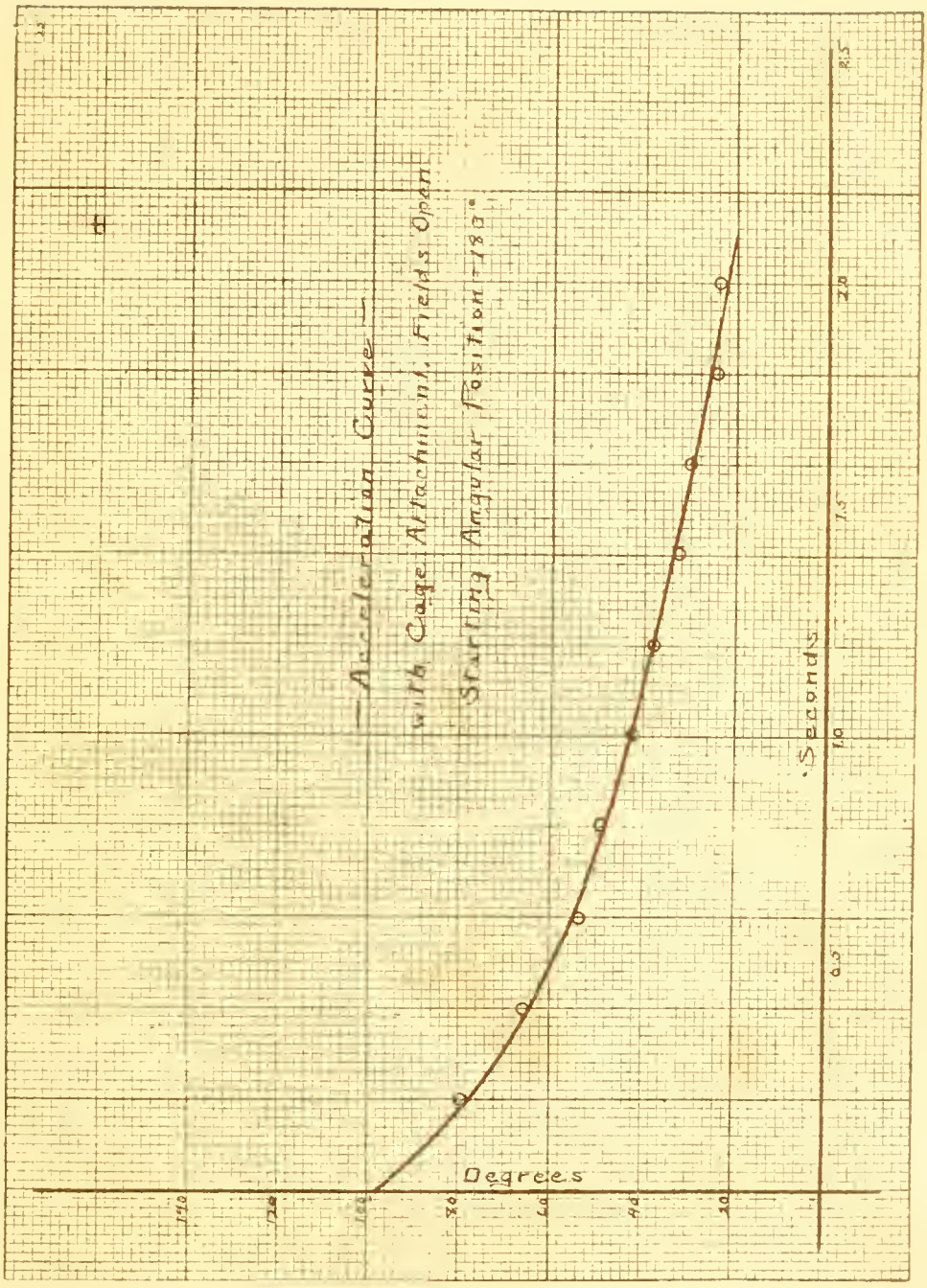
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE AYYACHMENT.

STARTING ANGLE 183°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	183.0		
10	230.0	47.0	
20	357.0	127.0	80.0
30	189.0	192.0	65.0
40	75.0	246.0	54.0
50	10.0	295.0	49.0
60	347.0	337.0	42.0
70	2.0	375.0	38.0
80	49.0	407.0	32.0
90	126.0	437.0	30.0
100	227.0	461.0	24.0
110	352.0	485.0	24.0

Starting acceleration from curve, -------- 93°

Starting torque, ---------- 108.6 ft.lbs.


—Acceleration Curve—
with Cage Attachment, Fields Open
Starting Angular Position = 180°
Degrees
Seconds

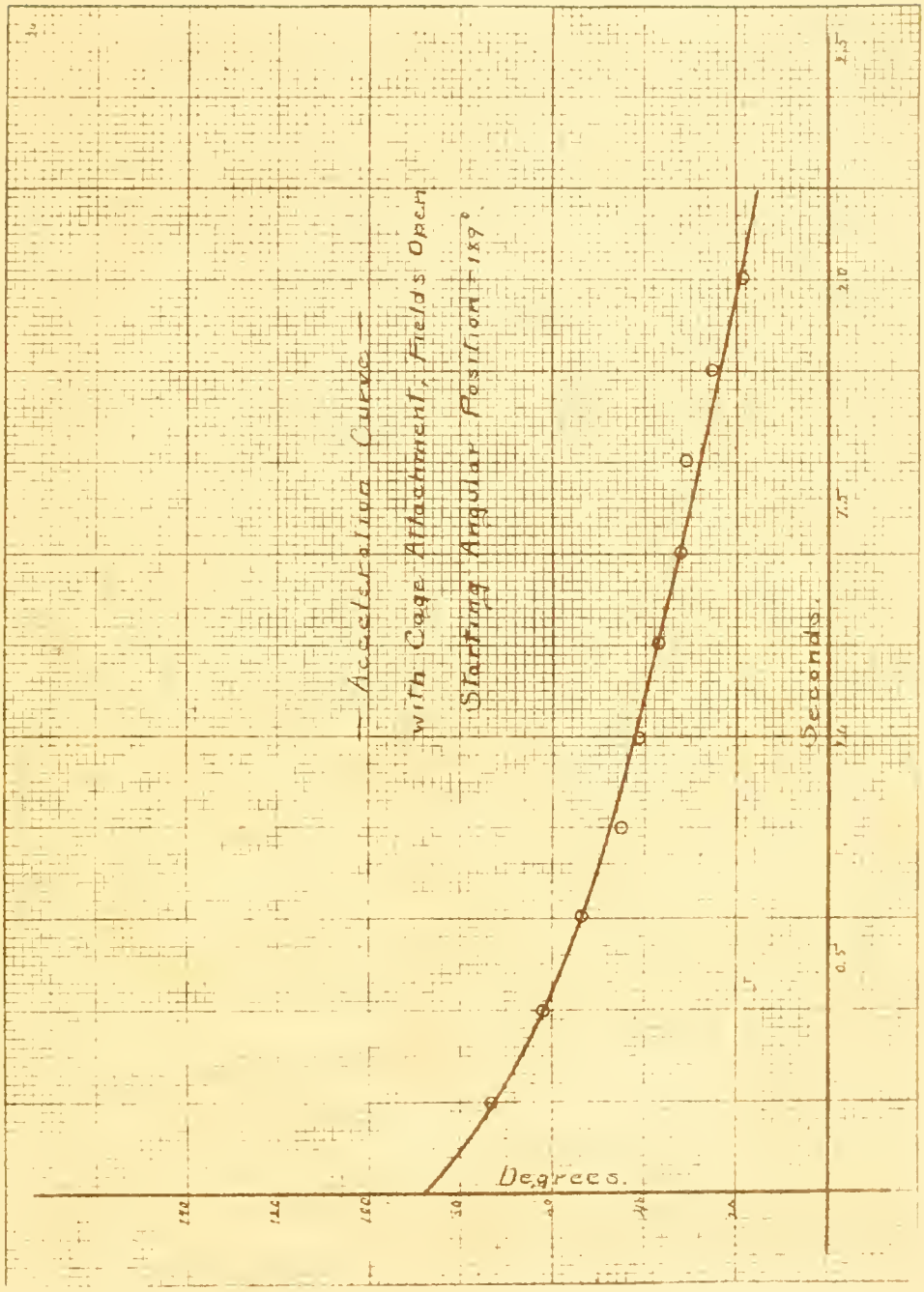
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT.

STARTING ANGLE 189°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	189.0		
10	232.0	43.0	
20	349.0	117.0	74.0
30	168.0	179.0	62.0
40	40.0	232.0	55.0
50	317.0	277.0	45.0
60	275.0	313.0	41.0
70	270.0	355.0	37.0
80	297.0	387.0	32.0
90	356.0	419.0	32.0
100	80.0	444.0	25.0
110	182.0	462.0	18.0

Starting acceleration (from curve), ------ 88°

Starting torque, ---------- 104.0 ft.lbs.


— Accelerating Curve —
with Cage Attachment, Field's Open
Starting Angular Position +189°
Degrees.
Seconds.

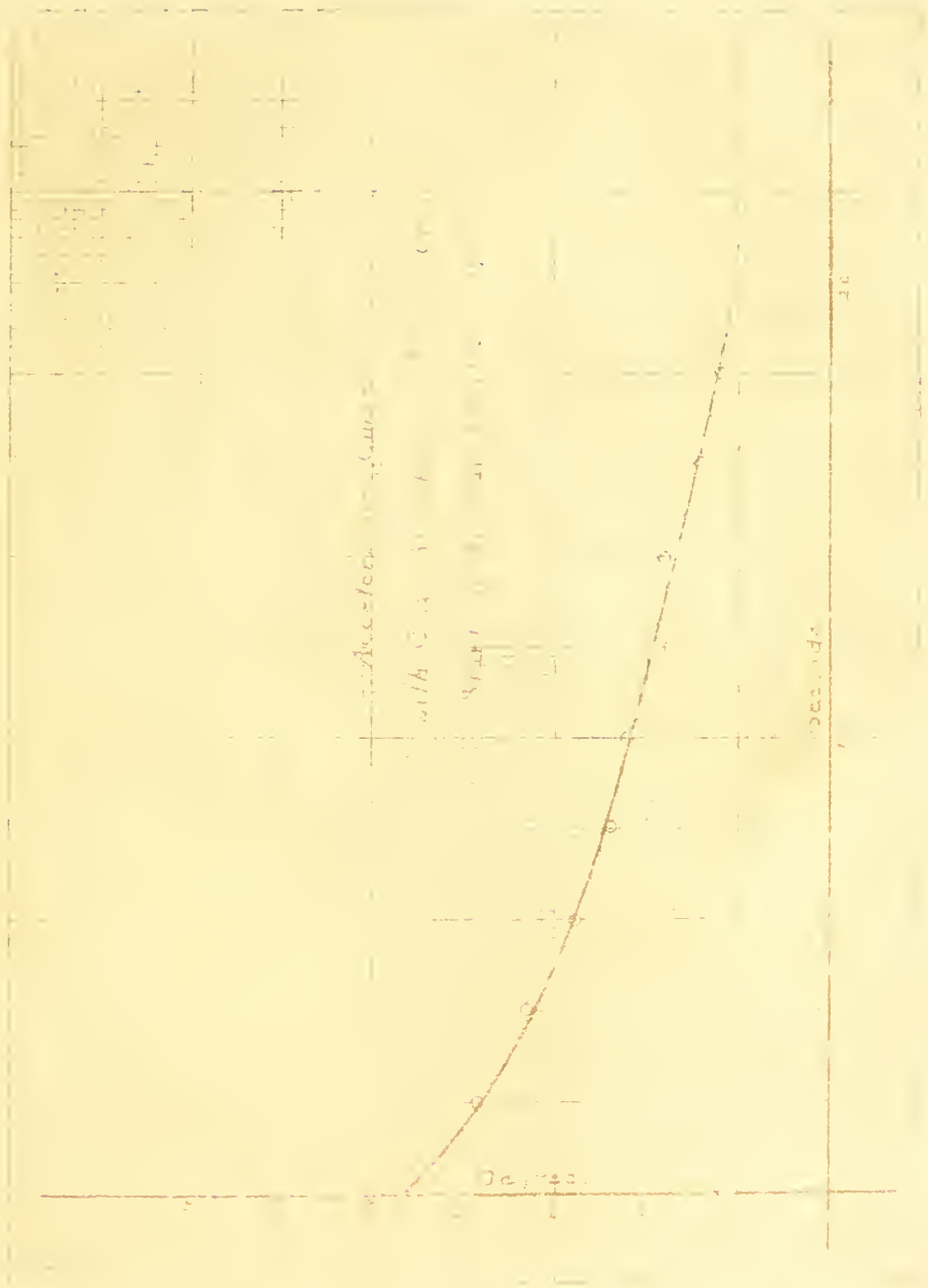
DETERMINATION OF THE TORQUE AT VARIOUS POSITIONS OF THE FIELDS, WITH CAGE ATTACHMENT.

STARTING ANGLE 195°

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	195.0		
10	244.0		
20	11.0	127.0	78.0
30	204.0	193.0	66.0
40	92.0	248.0	55.0
50	27.0	295.0	47.0
60	7.0	340.0	45.0
70	22.0	375.0	35.0
80	74.0	412.0	37.0
90	153.0	439.0	27.0
100	256.0	463.0	24.0

Starting acceleration (from curve), ------ 91°

Starting torque, ---------- 107.3 ft.lbs.



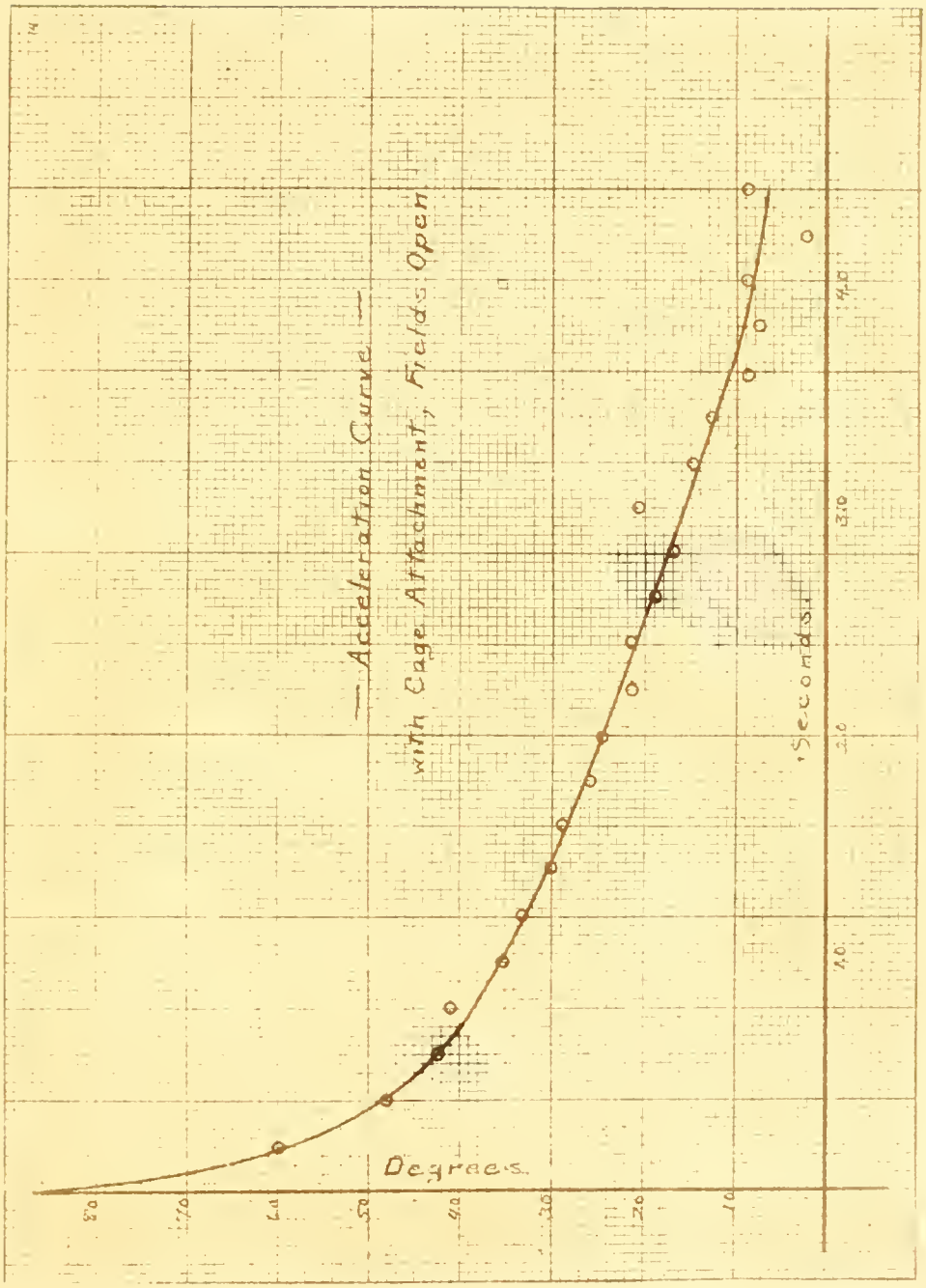
OTHER EFFECTS OF THE CAGE ATTACHMENT.

Noting the increase in the starting torque due to the action of the cage attachment, it was deemed to be of interest to ascertain the other effects of the cage attachment upon the operation of the motor. Because of the larger starting torque obtained with the cage attachment, the time required for the machine to approech synchronism is diminished. A comparison of the times may be made by an inspection of the following curves taken under various condition of operation.

DETERMINATION OF THE TIME REQUIRED

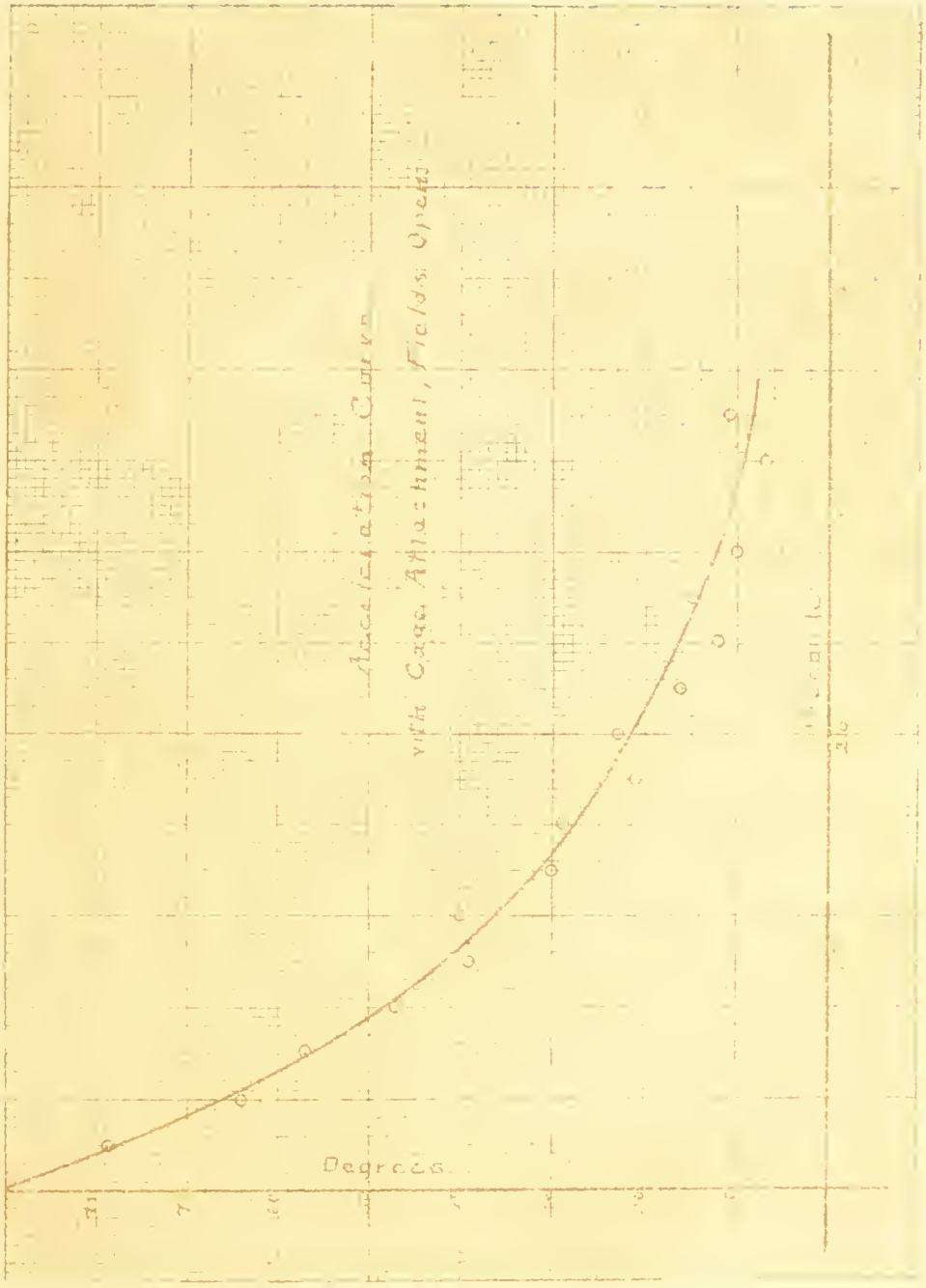
TO REACH SYNCHRONISM.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	268.0		
10	308.0	40.0	
20	48.0	100.0	60.0
30	200.0	152.0	48.0
40	34.0	194.0	42.0
50	269.0	235.0	41.0
60	179.0	270.0	35.0
70	122.0	303.0	33.0
80	95.0	333.0	30.0
90	97.0	362.0	29.0
100	125.0	388.0	26.0
110	178.0b	413.0	25.0
120	252.0	434.0	21.0
130	348.0	456.0	22.0
140	103.0	475.0	19.0
150	235.0	492.0	23.0
160	28.0	513.0	b 21.0
170	176.0	508.0	5.0
180	337.0	521.0	13.0
190	147.0	530.0	9.0
200	329.0	542.0	8.0
210	160.0	551.0	9.0
220	353.0	553.0	2.0
230	195.0	562.0	9.0


— Acceleration Curve —
with Cage Attachment, Fields Open
Degrees.
Seconds.

DETERMINATION OF THE TIME REQUIRED TO REACH SYNCHRONISM, WITH CAGE ATTACHMENT.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	320.0		
10	7.0	47.0	
20	133.0	126.0	79.0
30	323.0	190.0	64.0
40	210.0	247.0	57.0
50	144.0	294.0	47.0
60	117.0	333.0	39.0
70	131.0	374.0	41.0
80	175.0	404.0	30.0
90	248.0	433.0	29.0
100	342.0	454.0	21.0
110	99.0	477.0	23.0
120	232.0	493.0	16.0
130	17.0	505.0	12.0
140	177.0	520.0	15.0
150	347.0	530.0	10.0
160	164.0	537.0	7.0
170	348.0	544.0	7.0
180	183.0	555.0	11.0


Accelleration Curves
with Cage Attachment, Fields Speed
Degrees

DETERMINATION OF THE TIME REQUIRED

TO REACH SYNCHRONISM, FIELDS OPEN.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	268.0		
10	302.0	34.0	
20	28.0	86.0	52.0
30	157.0	129.0	43.0
40	325.0	168.0	39.0
50	167.0	202.0	34.0
60	41.0	234.0	32.0
70	304.0	263.0	29.0
80	237.0	293.0	30.0
90	196.0	319.0	26.0
100	181.0	345.0	26.0
110	192.0	371.0	26.0
120	226.0	394.0	23.0
130	283.0	417.0	23.0
140	359.0	456.0	19.0
150	95.0	456.0	20.0
160	208.0	473.0	17.0
170	337.0	489.0	16.0
180	122.0	505.0	16.0
190	279.0	517.0	12.0
200	86.0	527.0	10.0

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
210	263.0	537.0	10.0
220	88.0	545.0	8.0
230	281.0	553.0	8.0
240	123.0	562.0	9.0
250	330.0	567.0	5.0
260	183.0	573.0	6.0
270	40.0	577.0	4.0
280	261.0	581.0	4.0
290	125.0	584.0	5.0

DETERMINATION OF THE TIME REQUIRED

TO REACH SYNCHRONISM, FIELDS SHORTED ON EACH OTHER.

VIBRATIONS.	ANGLE.	VELOCITY.	ACCELERATION.
0	159.0		
10	171.0	12.0	
20	205.0	34.0	22.0
30	255.0	50.0	16.0
40	322.0	67.0	17.0
50	45.0	81.0	14.0
60	137.0	94.0	13.0
70	244.0	107.0	13.0
80	4.0	120.0	13.0
90	139.0	135.0	15.0
100	287.0	148.0	13.0
110	88.0	161.0	13.0
120	264.0	176.0	15.0
130	93.0	189.0	13.0
140	297.0	204.0	15.0
150.0	156.0	219.0	15.0

DETERMINATION OF THE TIME REQUIRED

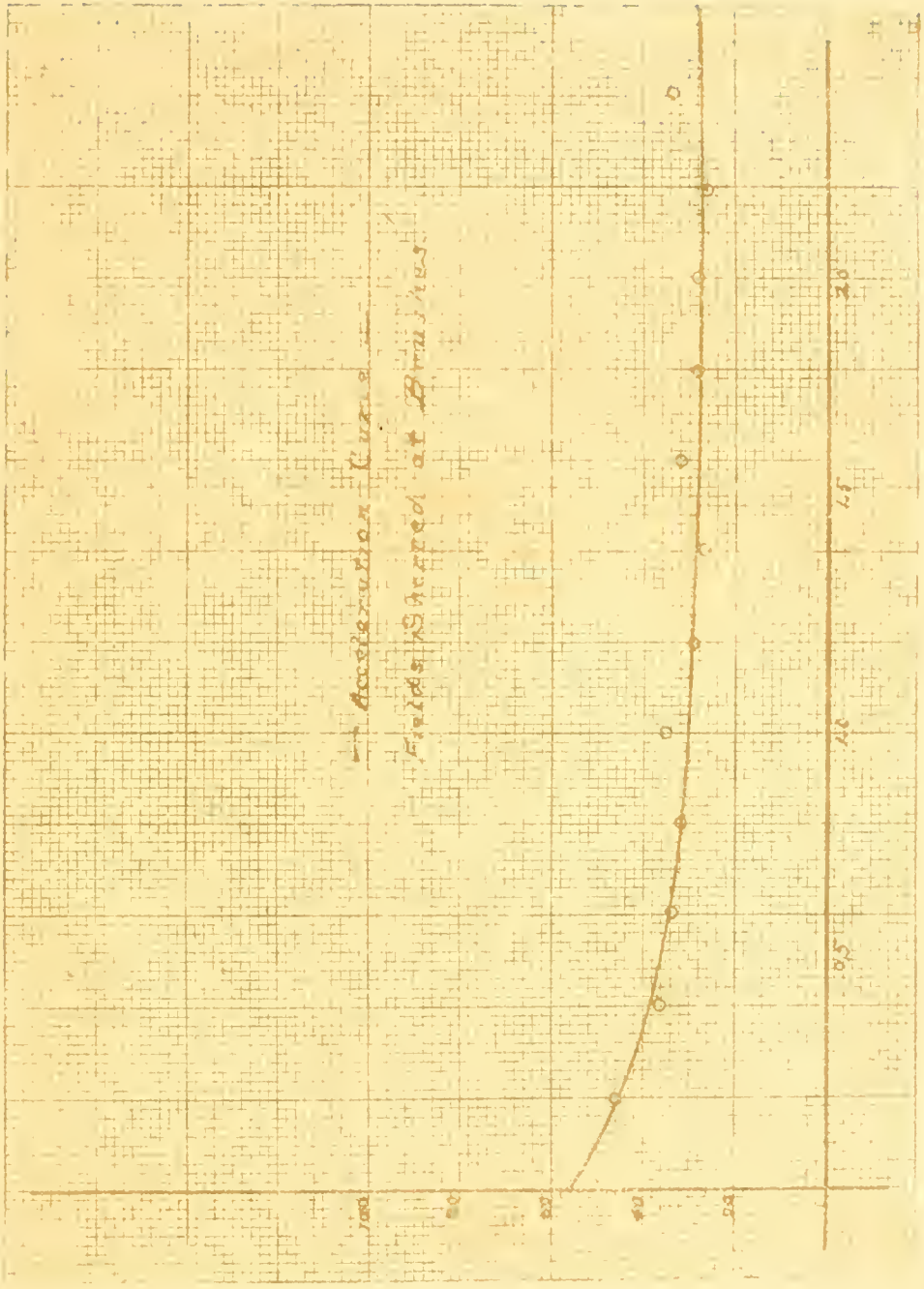
TO REACH SYNCHRONISM, FIELDS SHORTED AT THE BRUSHES.

VIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	129.0		
10	148.0	19.0	
20	189.0	41.I	22.0
30	249.0	60.0	19.0
40	326.0	77.0	17.0
50	60.0	94.0	17.0
60	170.0	110.0	16.0
70	295.0	125.0	15.0
80	74.0	139.0	14.0
90	227.0	153.0	14.0
100	55.0	168.0	15.0
110	218.0	183.0	15.0
120	56.0	198.0	15.0
130	269.0	213.0	15.0
140	136.0	227.0	14.0

DETERMINATION OF THE TIME REQUIRED

TO REACH SYNCHRONISM, FIELDS SHORTED AT THE BRUSHES.

VVIBRATIONS.	ANGLE.	ANGULAR VELOCITY.	ANGULAR ACCELERATION.
0	159.0		
10	170.0	11.0	
20	204.0	34.0	23.0
30	255.0	51.0	17.0
40	323.0	68.0	17.0
50	47.0	84.0	16.0
60	149.0	102.0	18.0
70	265.0	116.0	14.0
80	34.0	129.0	13.0
90	179.0	145.0	16.0
100	338.0	159.0	14.0
110	151.0	173.0	14.0
120	337.0	186.0	13.0
130.	180.0	303.0	17.0
140	37.0	217.0	14.0



EFFECT OF THE CAGE ATTACHMENT UPON THE VOLTAGE GENERATED IN THE FIELDS.

Since the voltage generated in the open fields at starting is considerable, and may be injurious to the insulation, experiments were performed to determine the effect of the cage attachment on this voltage. This was done in the following manner:- The rotor was blocked, and the armature circuit closed long enough to take the reading of the voltmeter placed across the terminals of the fields. The cage, however, seemed to have no effect upon the voltage generated. The data obtained was as follows:-

Without cage, ...	1480 volts.
With cage , ...	1385 volts.

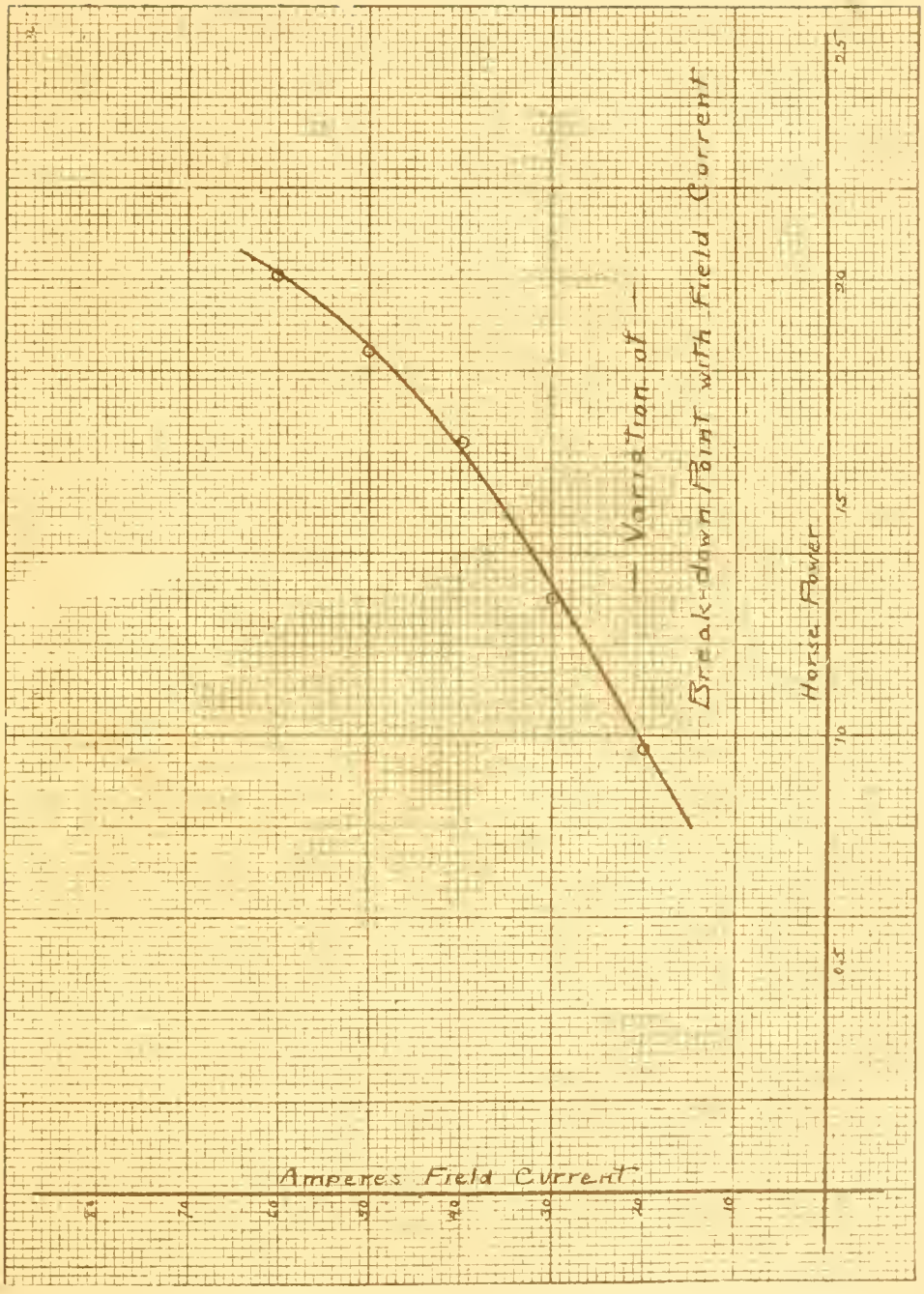
THE EFFECT UPON THE BREAK DOWN POINT.

It was thought that the cage attachment would have some effect upon the break down points. Consequently a series of runs was made, with and without the cage, using various field currents, the load being varied up to the break down point, and curves were plotted from the data obtained. It was found that the break down curves varied but slightly from each other.

VARIATION OF THE BREAK DOWN POINT WITH FIELD CURRENT.

BREAK ARM -- 18". DEAD WEIGHT ON SCALES -- 11#

FIELD CURRENT.	SCALE READING.	NET WEIGHT.	HORSE POWER.
1.0	70.0	59.0	8.45
2.0	79.0	68.0	9.71
3.0	102.0	91.0	13.00
4.0	126.0	115.0	16.43
5.0	140.0	129.0	18.43
6.0	152.0	141.0	20.14


— Variation of —
Breakdown Point with Field Current
Horse Power
Amperes Field Current

VARIATION OF BREAK DOWN POINT WITH FIELD CURRENT

CAGE ATTACHMENT.

BREAK ARM -- 18". DEAD WEIGHT ON SCALES-- 11#

FIELD CURRENT.	SCALE READING.	NET WEIGHT.	HORSE POWER.
1.0	49.0	38.0	5.43
2.0	81.0	70.0	10.00
3.0	103.0	92.0	13.14
4.0	123.0	112.0	16.00
5.0	138.0	127.0	18.14
6.0	141.0	130.0	18.57

Field Current in Amperes
Horse Power
Curve from of
Break-down Point with Field Current,
with Edge Attachment

THE EFFECT UPON THE POWER FACTOR.

The next feature investigated was the effect of the cage upon the power factor. With the rotor blocked, the starting conditions were maintained for a period of sufficient duration to make the required readings necessary to obtain the power factor. In order to determine the power factor for the desired voltage a run was made for various voltages, and the results plotted. The readings taken were the line voltage, the line current, and the wattmeter reading. The power factor was determined from these by the equation,

$$P.F. = \frac{2\,W}{\sqrt{3}\;E\;I}$$

where W is the wattmeter reading,

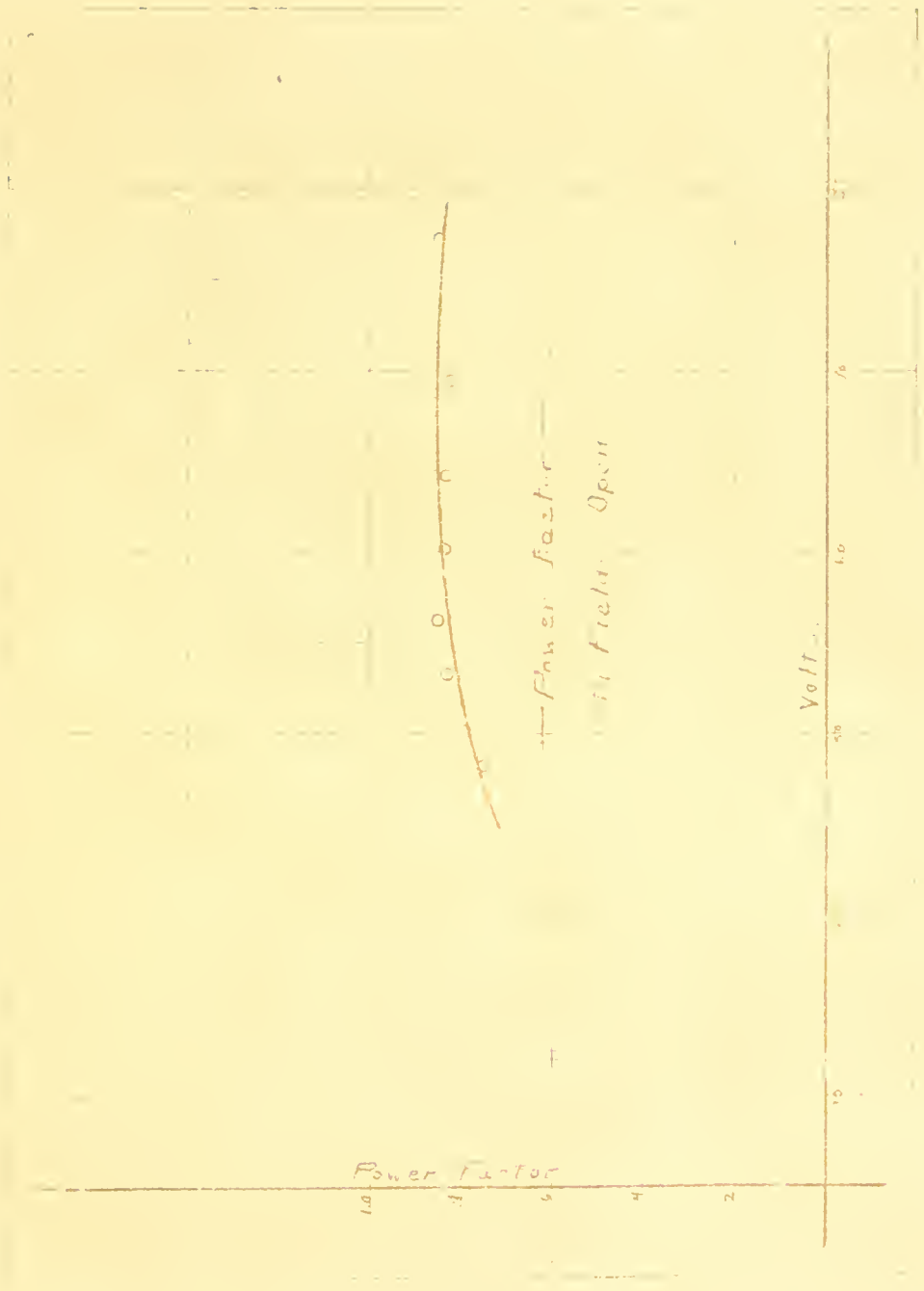
E is the voltage,

I is the current,

A higher power factor was obtained by means of the cage attachment than was obtained without it.

POWER FACTOR.

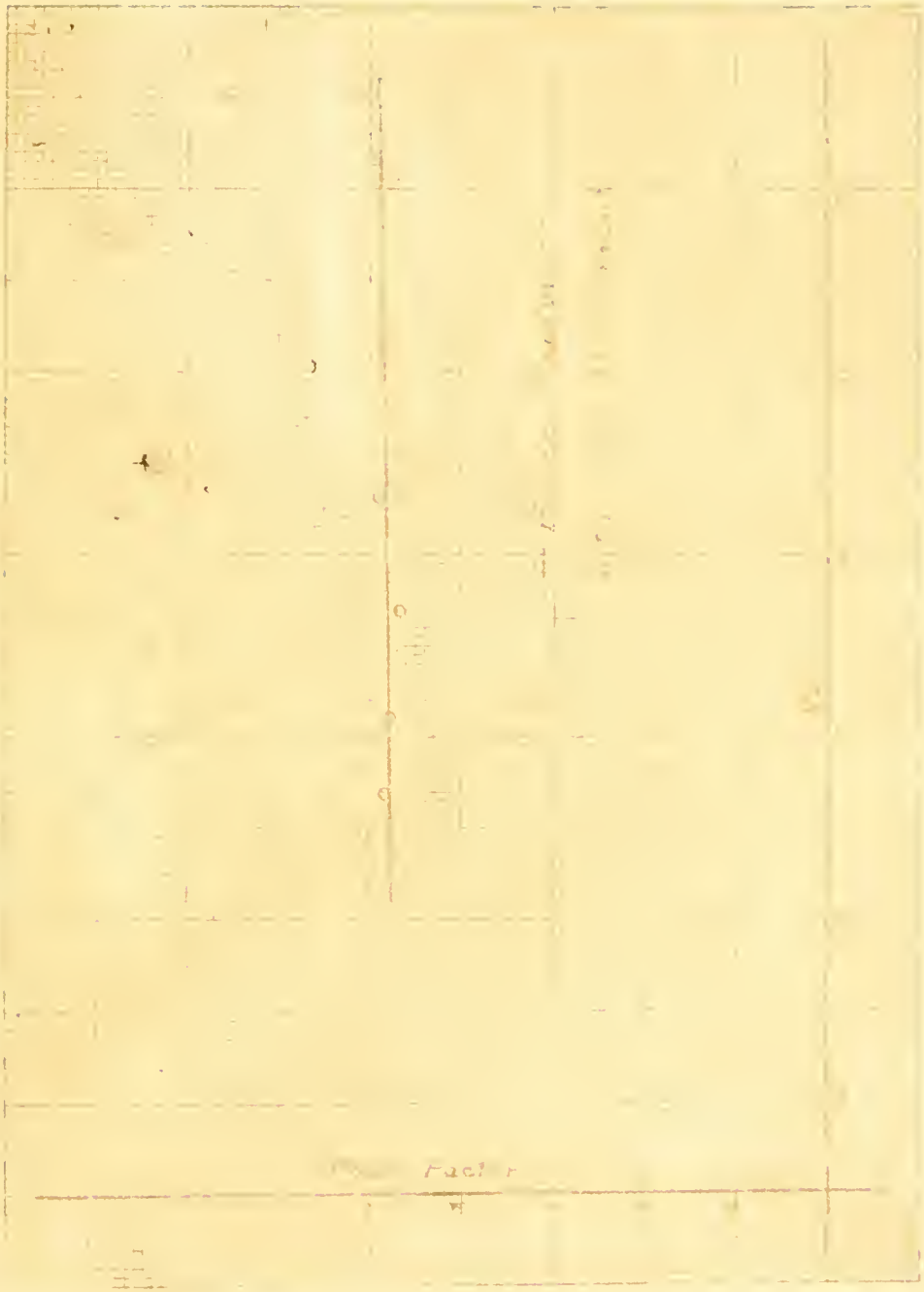
CURRENT.	VOLTAGE.	KILO-WATTS.	POWER FACTOR.
138.0	77.5	8.0	.844
117.5	70.0	6.0	.820
105.5	65.0	5.1	.850
98.0	61.0	4.5	.854
89.0	57.0	3.82	.850
83.0	54.0	3.40	.826
78.0	51.0	2.90	.782
73.6	49.0	2.60	.750


Power factor
Volt
Power factor
1.0
.8
.6
.4
.2

POWER FACTOR

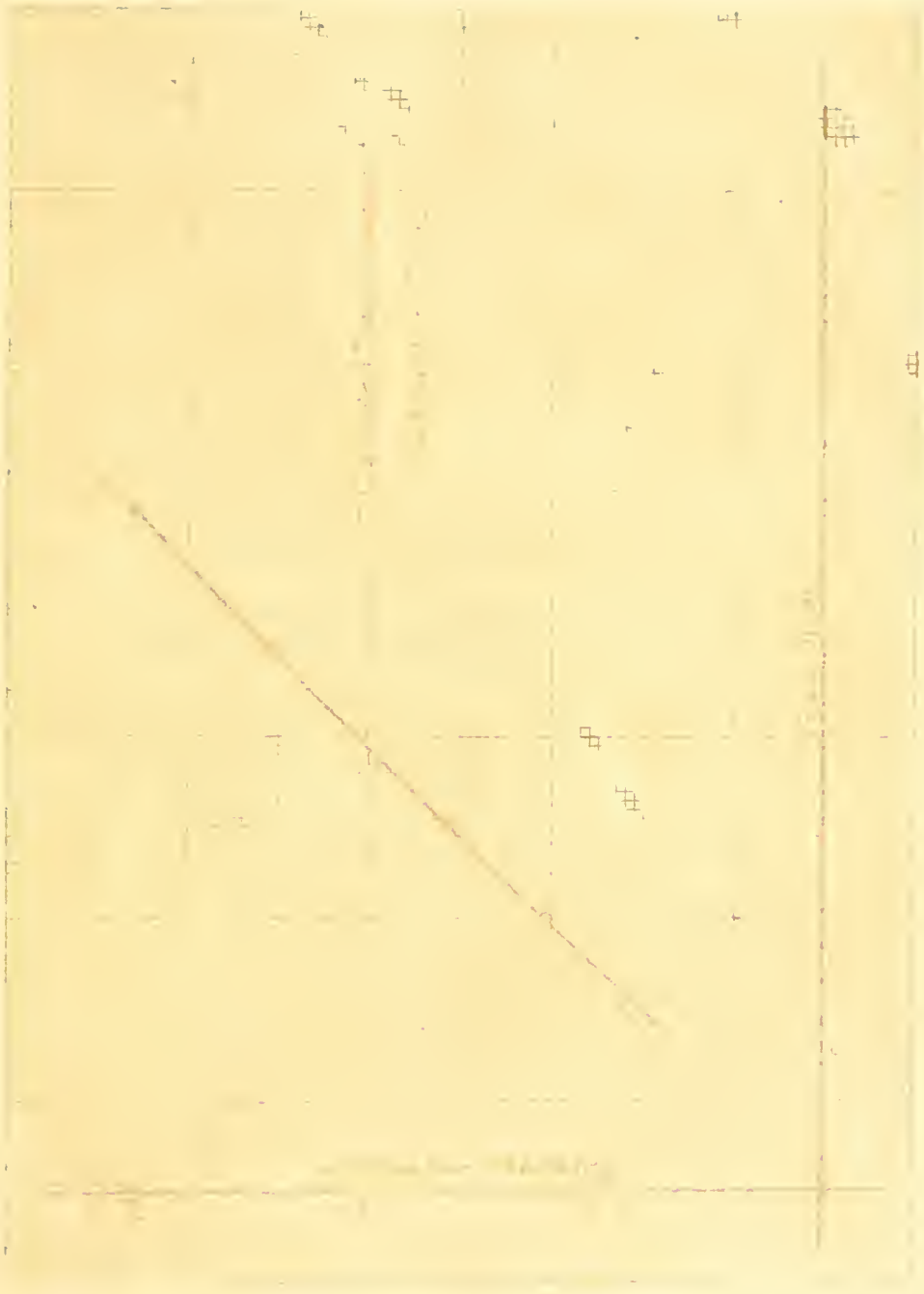
WITH CAGE ATTACHMENT.

CURRENT.	VOLTAGE.	KILO-WATTS.	POWER FACTOR.
210.	81.8	14.7	.99
182.	71.5	10.95	.97
160.	63.2	8.56	.98
141.	56.8	6.53	.94
134.	51.0	5.28	.96
112.	47.0	4.41	.97



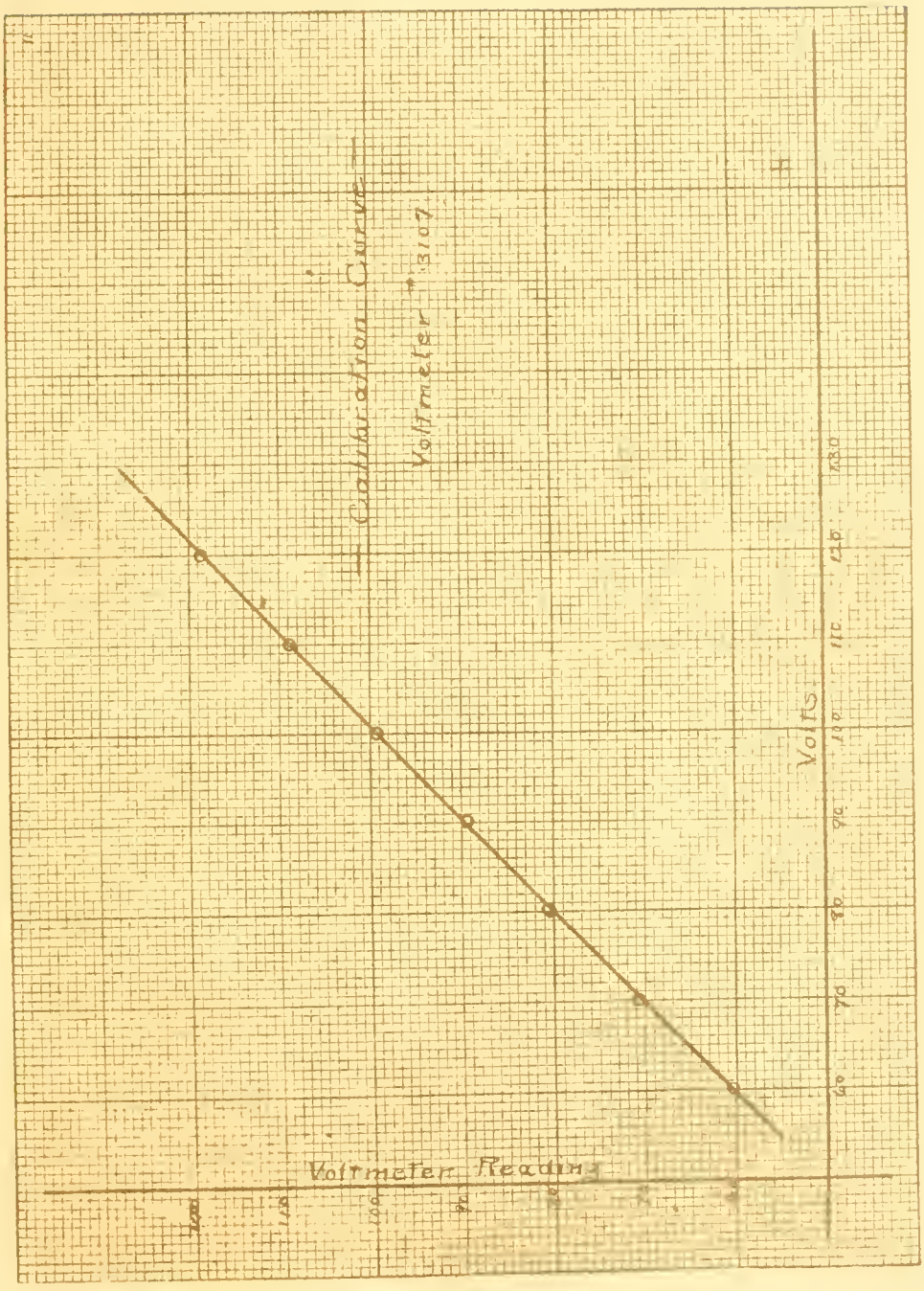
CALIBRATION OF WATTMETER #512.

KILO-WATTS.	WATTMETER READINGS.	REVERSED READINGS.	AVERAGE READINGS.
4.0	4.05	4.45	4.25
6.0	6.52	5.72	6.12
8.0	7.55	8.80	8.18
10.0	10.98	9.40	10.19
12.0	11.22	13.20	12.21
14.0	15.40	13.08	14.24
15.0	13.93	16.44	15.19



CALIBRATION OF VOLTMETER #3107.

TRUE VOLTS.	VOLTMETER READINGS.	REVERSED READINGS.	AVERAGE READINGS.
60.0	61.5	60.2	60.8
70.0	70.0	71.1	70.5
80.0	80.8	79.6	80.2
90.0	89.3	90.3	89.8
100.0	99.7	99.0	99.3
110.0	108.7	109.4	109.0
120.0	118.4	118.2	118.3


Calibration Curve
Voltmeter #3107
Volts
Voltmeter Reading

RESUME.

In conclusion, we are able to say that the shorting of the fields either upon themselves or as a whole, produces a decidedly detrimental effect, the largest starting torque being obtained when the fields are open. However, this condition may be greatly improved upon, by the application of the cage attachment. This arrangement has the still further advantages of giving a higher power factor, and has a tendency to prevent hunting.